A TEXT-BOOK ON FOREST MANAGEMENT

By M. R. K. JERRAM, M.C.

Assistant Lecturer in Forestry,
University College of North Wales, Bangor.

It is the object of this book to bring to the notice of the student, in as brief and simple a manner as possible, all matters of primary importance relating to the subjects which are commonly dealt with under the term Forest Management. It is not intended to displace the study of those authors who deal with these subjects individually at much greater length; but it does represent an endeavour to introduce the student to all the more important problems involved, to explain the elementary principles on which their solutions are based, and to provide a framework on which a fuller knowledge may be built up by lectures, reading and study of practice in the forest itself.

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PREFACE

It is the object of this book to bring to the notice of the student, in as brief and simple a manner as possible, all matters of primary importance relating to the subjects which are commonly dealt with under the term Forest Management. It is not intended to displace the study of those authors who deal with these subjects individually at much greater length; but it does represent an endeavour to introduce the student to all the more important problems involved, to explain the elementary principles on which their solutions are based, and to provide a framework on which a fuller knowledge may be built up by lectures, reading and study of practice in the forest itself.

The requirements of forest students of past generations in the above respects were met by Volume III of Schlich's *Manual of Forestry;* but, now that that work is out of print, and, in some respects out of date, the necessity for some book on similar lines, which will economize the time of lecturers in explaining and illustrating elementary matters, and of students in taking notes, is apparent.

Some explanatory remarks on the arrangement and treatment of the subject matter are perhaps required:—On the principle that pictures are more easily memorized than figures and that their significance is more obvious, I have, in dealing with the relationships between the Growing Stock, Increment and Yield in Part I, Chapter II, made a more extensive use of geometrical methods than is usual. Having regard, firstly, to the fact that this book is intended primarily for students whose future work may lie in any part of the British Empire, and who therefore may be required to deal with a great diversity of conditions, and secondly to the fact that most systems of yield regulation have been evolved to meet the conditions in a particular locality and that their number is constantly being added to, I have avoided entering into details regarding the application of a large number of different systems. There are a few basic principles on which all methods are founded. These have been explained, and selected examples given of their application. These examples have been selected rather for their value

in illustrating principles than as representing methods of general applicability. Whilst a general knowledge of what others have done is of value to the forester, he cannot rely upon extracting from a book a ready-made system which he can apply without modification.

In Part III under Forest Finance I have dealt briefly with the essentials of forest valuation and economics and have endeavoured to make these subjects intelligible to those with very little mathematical knowledge.

I have followed the method introduced by Messrs. R. Bourne and C. E. Simmons at the School of Forestry, Oxford University, of bringing the regulation of the yield into relation with silviculture by classifying the latter as Regular or Irregular (p. 14). I am also indebted to them for the method of introducing the subject of Forest Valuation by means of the Capital Account (Part III, Chapter IV) and to Mr. Simmons for permission to use his examples and tables illustrating this method (pp. 116, 118, 119, 123). The list of Working Plan headings in Part II also follows in the main that drawn up by Mr. Bourne.

I am indebted to Mr. A. D. Blascheck, late Inspector-General of Forests, India, for very kindly going through this work and making many valuable suggestions for its improvement.

I am grateful to Lady Schlich for her kind permission to make use of the late Sir William Schlich's work ; and to those author's whose published experience has been drawn upon. Specific references are made in the footnotes.

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PART I. THE FOUNDATIONS OF FOREST MANAGEMENT

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PART I

THE FOUNDATIONS OF FOREST MANAGEMENT

INTRODUCTION

*(Schlich, Vol. III, p. 167, *The Foundations of Forest Management.* Also Jackson's *Short Manual of F.M.*, Section 6, "The Wood Capital.")

FOREST management in a broad sense denotes the application of the knowledge which has been acquired in all branches of forestry and the allied sciences to the management of forests in the interests of man.

The first duty of a manager of a property is to ascertain the wishes of the owner. He will then apply his knowledge towards designing a plan of management, calculated to meet these wishes in the most effectual manner possible. The instrument which applies this knowledge to the carrying out of the wishes of the owner in the case of a forest property is known as the Forest Working Plan.

Forests are maintained either for their:

Physical effects, or for
Productive purposes.

To the former class belong forests maintained for the protection of mountain slopes, catchment areas, park lands, game preserves, etc. To the latter belong forests maintained for the production of minor produce such as bark, resin, etc., or of major produce, *i.e.*, wood.

* The references under section and chapter headings are to other works dealing with the same subject which may be read with advantage by the student. References to Schlich are to the 5th edition of his Manual.

The forests maintained for productive purposes, and specially for the production of timber, are by far the most important and extensive, and the economic management of such forests raises special problems which must be dealt with before we shall be in a position to draw up a working plan for their management. These problems arise in connection with the calculation and regulation of the yield, and the term "forest management" is often used in a narrower sense to designate this branch of forestry only.

Regarded from the productive and economic point of view, a tree or a wood represents an investment of which the annual income (increment) is inseparable from the capital (growing stock), which produces that income. Any tree or wood represents the sum of the annual accretions laid on up to date by that wood and the current year's accretion of new wood is indistinguishable from the old wood or wood-capital which produced this accretion. In order, therefore, that forestry may be carried on on sound economic principles, under which the capital is preserved and a steady income maintained, it is necessary to devise a method by which the income shall be distinguishable from the capital, so that the former only is removed in fellings. The simplest method of attaining this end is to maintain a complete succession of equal areas of all age gradations from one year old up to the age of maturity so that a mature wood, representing the true increment on the whole, may each year be available for felling. Thus, if 100 acres of forest comprising 1 acre of each age gradation from 1 year old to 100 years old be maintained, there will be available in perpetuity an acre of 100-years-old timber available for felling annually. The difficulty of harvesting each year the annual production of each acre is solved by harvesting the accumulated production of 100 years on one-hundredth part of the whole area.

The establishment of such a series of age gradations as the above is known as management for a sustained yield. In practice any management which aims at an approximate equalization of the yield, annual or even periodic (provided the periods are short), will come under this definition, as opposed to management for an intermittent yield, where each crop is treated as a separate unit, in no relation to any other unit, and is felled when considered mature. Management for inter-

mittent yields is not without its advantages. It is extremely simple; it permits the felling of each crop when it is ripe, and does not, therefore, necessitate the sacrifice of material which the establishment of the series of age gradations, required by management for a sustained yield, sometimes involves; nor do unforeseen occurrences, such as extensive destruction by wind or other agency, cause the same embarrassment as they do in the case of the latter. Such considerations, and the desire to accumulate a sum of money for some special purpose, may decide an owner of a small property to prefer such form of management. But generally—and almost always in the case of large estates—marketing, labour and financial considerations will necessitate a system of management which yields a regular supply of material.

The yield from a forest is obtained, of course, not only from final fellings but also from those silvicultural operations, such as thinnings as are required during the life of any wood. Whether or not the yield from such operations is taken into consideration in equalizing the total annual yields will depend on economic considerations and the silvicultural methods employed. It is usually possible to arrange, within the framework of a plan of management, which will provide equal final yields, for approximately equal intermediate yields in so far as they are of economic importance. Generally speaking, therefore, only the former need to be considered in framing a plan of management to produce a sustained yield. During the process of building up a G.S. capable of producing such a sustained yield, the yield ~~for~~ subsidiary operations is, however, often used for the purpose of equalizing the yield of marketable material. The objection that it is impossible to regulate in advance by time and yield such purely silvicultural operations as thinnings has usually more weight in theory than in practice. In practice silviculture seldom requires that a wood should be thinned in any particular year and the future yield in thinnings can often be estimated with sufficient accuracy from past experience.

Where a forest is to be formed by planting or sowing and clear felled when mature, the establishment of the series of age gradations referred to above follows automatically on the execution of a simple plan of management. The forester, however, is more often faced with an already existing forest

in which there is no clear line of demarcation between the age gradations, and in which silvicultural requirements impose an insuperable barrier in the way of the establishment of even-aged woods. It is in such forests that the problem of calculating the actual proportion and the correct proportion of the increment to the growing stock is most difficult, and it is this problem which will be dealt with in the following chapters.

CHAPTER I

Preliminary Matters Relating to the Regulation of the Yield

I. *Classes of Forest dealt with*

Forests required to be managed for a sustained yield of major produce will be found to fall into one of the following classes:

(*a*) Forests forming part of an afforestation scheme, which is not yet sufficiently far advanced for mature woods to be available for felling.

(*b*) Forests containing mature woods artificially established, which, however, have not been scientifically managed with a view to a sustained yield.

(*c*) Natural forests still in the first rotation of scientific management.

(*d*) Forests which have been under scientific management with the object of obtaining a sustained yield for a rotation or longer.

Types (*a*) and (*b*) are found in Great Britain, and type (*c*) in the British dominions and colonies, but type (*d*), except in the form of coppice or coppice with standards, is at present almost confined to the continent of Europe.

II. *The Normal Forest*

It is the last class of forest mentioned above which provides most examples for the demonstration of principles, for only here will be found forests approaching the ideal Normal Forest, the establishment of which is the aim of all management for a sustained yield. A normal forest may be defined as one which contains a regular and complete succession of age gradations or classes (several age gradations thrown together) in the correct proportion so that an annual or periodic felling of the ripe woods results in an equalization of the annual or periodic yields. It provides a standard by which an existing

forest may be judged, an ideal which may be aimed at (even if it is seldom reached) and an easily conceivable (if non-existent) forest, in which the relationships of the rotation, growing-stock and yield can be expressed with some degree of accuracy by mathematical formulæ. It is not necessary for the conception of a normal forest that the age classes or gradations should be on separate areas, but it is of great assistance in putting the conception to practical use if this can be assumed. For example, the intermingling of the age classes under the Selection System, and the consequent difficulty in recognizing to what extent their proportion differs from normal, constitutes the main difficulty in regulating the yield in such forests.

The above succession of age gradations or classes is known as a NORMAL SERIES OF AGE GRADATIONS or CLASSES and the sum of their volumes is known as the NORMAL GROWING STOCK. The NORMAL INCREMENT is the increment laid on by a normal forest. The total G.S. or increment in a forest may be equal in volume to the normal G.S. or increment though the forest is in an abnormal condition, for a deficiency in volume or increment of any one class may be made up by an excess in another class. Only the presence of a normal series of age gradations will constitute a normal forest. It is clear also that a forest can only be normal in relation to a certain method of treatment and rotation. If the rotation of a normal forest be changed it is obviously no longer normal.

The normal forest is an essential conception for a proper understanding of the principles of yield regulation. In practice, however, undue haste in the pursuit of the normal may constitute a danger to the property. The establishment of a normal forest, particularly a very regular one where different age classes occupy separate areas, simplifies all the operations with which management is concerned, such as the calculation of the yield, budget arrangements, extraction of produce, supply of markets, etc. It is natural, therefore, for management to strive for its early attainment. In some cases Nature is accommodating and throws no obstacle in the way of progress along the desired path. But in others the treatment which would seem to be required for immediate advance towards the normal and for simplification of management is one to which the existing crop is unable to respond. In such cases only a

comprehensive knowledge of the local ecological conditions and the limitations they impose—a knowledge required both on the part of those responsible for the plan of management and those responsible for its execution—will ~~enable a balance to be maintained between the desirable and the practicable.~~

III. The Increment

(Schlich, Vol. III, pp. 178-184. Chapman's *Forest Management*, 1931, p. 290.)

The methods of measuring volume will have been learnt under Forest Mensuration. The increase in volume each year is known as the Current Annual Increment (C.A.I.). The volume of a tree or wood at any age is the sum of the current annual increments for each year up to that age. The mean of all the current annual increments is known as the Mean Annual Increment (M.A.I.). Thus the M.A.I. at any age is equivalent to the volume at that age divided by the age.

**Example:* A wood aged 40 has a volume of 4,000 cubic feet and at 41 a volume of 4,070 cubic feet.

C.A.I. = 70 cubic feet and M.A.I. at 41 years $= \frac{4{,}070}{41} =$ 99·3 c.ft.

If the M.A.I. is that for the whole rotation, it is sometimes necessary to distinguish it as the Final Mean Annual Increment and, if there is a regular yield from thinnings, it will be final crop plus sum of all thinnings divided by the rotation (*vide* next section).

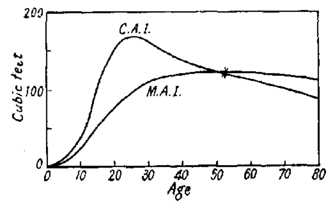
Very little observation is required to show that the annual growth (C.A.I.) is small in the seedling stage, becomes progressively greater and, after attaining a maximum, falls until it approaches zero or death supervenes. More detailed investigations have shown that in the case of light demanders and moderate shade-bearers, this maximum is reached about the time when the height growth culminates, and, in the case of shade-bearers, usually several years later, also that after the

* In this and the following examples one-year intervals are used for the purpose of illustration. In practice, as explained later, woods are only measured at intervals of several years.

maximum is attained the C.A.I. falls rapidly at first and then more slowly.

The progress of the C.A.I. may be represented by a curve as in Fig. 1.

Since the M.A.I. is merely the average of the current annual increments to date there must be definite mathematical relationships between the two at all ages. These relationships



[FIG. 1.—C.A.I. AND M.A.I. OF LARCH.

are of importance in forestry and are as follows, as illustrated in Fig. 1, giving the M.A.I. per acre for larch. They depend, of course, on the nature of the curve for the C.A.I.

(1) The M.A.I. keeps at first below the C.A.I.
(2) The C.A.I. attains its maximum before the M.A.I. and will be falling whilst the latter is still rising.
(3) Whilst the C.A.I. > M.A.I. the latter is rising.
When the C.A.I. < M.A.I. „ „ „ falling.
When the C.A.I. = M.A.I. „ „ „ stationary.

Or in other words, at the time when the C.A.I. and M.A.I. curves meet the latter has attained its maximum.

This point is of importance in dealing with the length of time a crop should be allowed to grow before it is harvested and will be referred to again when dealing with Rotation.

It is often more convenient to determine and use the C.A.I. rather than the M.A.I., and use may be made of the fact that for several years about the point of culmination of the latter no serious practical error results from assuming that C.A.I. = M.A.I. The C.A.I. can, however, never be accurately determined for one year; in practice it will always be measured over a period, and whenever the term is used it is accepted as meaning the average annual increment over a short period.

For the purposes of yield calculation and control it is often useful to determine the proportion which exists between the increment and volume at various stages in the life of a wood. This proportion is obtained independently of the actual volume by calculating the C.A.I. per cent.; thus

Volume of a wood now $= V$
Volume of the wood n years ago $= v$

$$\text{C.A.I.} = \frac{V - v}{n}$$

$$\text{Average volume producing C.A.I.} = \frac{V + v}{2}$$

$$\text{Increment \%} = p = \frac{\text{Increment}}{\text{Volume}} \times 100 = \frac{\frac{V - v}{n}}{\frac{V + v}{2}} \times 100$$

$$= \frac{V - v}{n} \times \frac{2}{V + v} \times 100$$

$$= \frac{V - v}{V + v} \times \frac{200}{n}.$$

This is known as PRESSLER'S formula. It assumes that the increment is laid on in equal portions during the n years and gives sufficiently accurate results for practical purposes provided the period n is a short one.

If any felling has been made in the intervening period its volume must obviously be added to V to obtain the correct result.

Example: Let the volume at the age of 40 = 2,000 c.ft., and in the year 50 = 3,000 c.ft., whilst a thinning in the year 45 gave 200 c.ft., then

$$p = \frac{3{,}000 + 200 - 2{,}000}{3{,}000 + 200 + 2{,}000} \times \frac{200}{10} = 4{\cdot}62\%.$$

IV. Effect of Thinnings on Increment

It has been stated that the rise and fall of the C.A.I.—on which the mathematical relationships between the C.A.I. and the M.A.I. depend—is a regular one. This is correct provided

the growing conditions remain constant; and, since the measurements on which the relationships are based refer to several years' growth, the regularity will not be upset by minor seasonal variations of rainfall, temperature, etc. A heavy thinning in a previously neglected wood may, however, result in checking the downward trend of the C.A.I. curve and even cause a second rise.

Apart from this, however, thinnings, whether natural or artificial, which take place in a wood, introduce a complication which does not arise when the increment of single trees is being considered. The mathematical relationships between the C.A.I. and the M.A.I. depend upon all the measurements being made on the same growing body, and this is a condition which cannot be obtained in the case of a wood the composition of which is being continually altered by the removal of part of the crop in thinnings. This being so we cannot expect to find in practice that the relationships between C.A.I. and M.A.I. are exactly as has been stated above, and, where we would draw conclusions from their relationships we must take precautions to ensure that in so far as is possible we are measuring the same crop.

Since yield tables trace the progress of an average fully stocked acre of wood throughout its life, or alternatively show the situation at any time in a normal series of 1-acre age gradations, their study will enable us to appreciate the extent to which the relationships stated to exist actually do obtain and will indicate the errors which may arise. General conclusions, however, cannot be drawn from one set of yield tables.*

To make the matter clear, the yield table given on p. 11 in which the several current annual and mean annual increments have been worked out, may be studied, together with the graphs in Fig. 2.

The usual method of determining the C.A.I. of a wood is to thin it, measure it now and measure it again after an interval of years *before* thinning, deduct the first measurement from the second and divide by the number of years which has elapsed between the two measurements. This is what has been done in Column 9 of the table on p. 11 (C.A.I. curve (1)). Com-

* Owing probably to the heterogeneous nature of the woods from which they were prepared the British Yield Tables show extremely irregular C.A.I. curves.

FROM LOREY'S YIELD TABLE FOR SILVER FIR, I QUALITY IN S. GERMANY
(from Schlich).

AGE.	VOLUME.				M.A.I.			C.A.I.		
(*a*)	*Main Crop.*	*Thinnings.*	*Total.*	*Total Production.*	(1)	(2)	(3)	(1)	(2)	(3)
	V	T	V+T	V+ΣT	$\frac{V+\Sigma T}{a}$	$\frac{V+T}{a}$	$\frac{V}{a}$	$\frac{V''+T''-V'}{10}$	$\frac{V''+T''-(V'+T')}{10}$	$\frac{V''-V'}{10}$
1	2	3	4	5	6	7	8	9	10	11
30	500		500	500	17	17	17			
40	1700	60	1760	1760	44	44	42	126	126	120
50	3670	360	4030	4090	82	81	73	233	227	197
60	5700	570	6270	6690	111	104	95	260	224	203
70	7960	1000	8960	9950	142	128	114	326	269	226
80	10350	1290	11640	13630	170	145	129	368	268	239
90	12550	1430	13980	17260	192	155	139	363	234	220
100	14290	1360	15650	20360	204	**156**	143	310	167	174
110	15780	860	16640	22710	**206**	151	**143**	255	99	149
120	16990	710	17700	24630	205	147	142	192		121

paring these figures with those obtained for the M.A.I. by dividing the standing volume before thinning by the age (*vide* Column 7, M.A.I. curve (2)) it will be seen that the M.A.I. at the age of 100, when it culminates, is much less than the C.A.I. The M.A.I. which is comparable with the C.A.I. in Column 9, is that obtained by adding to the standing volume the total yield from thinnings to date, and dividing by the age (*vide* Column 6, M.A.I. curve (1)). But information regarding the yield from thinnings throughout the life of a wood is not

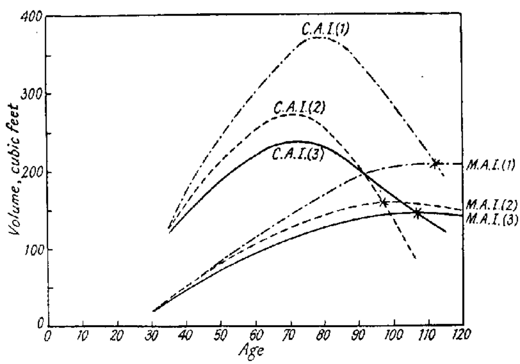


FIG. 2.—EFFECT OF THINNING ON C.A.I. AND M.A.I.

always available in cases where it is desired to compare the M.A.I. with the C.A.I. In such cases either both measurements should be made before thinning, as in Columns 7 and 10, or both after thinning, as in Columns 8 and 11.

V. The Rotation

The Rotation is the period which elapses between the formation of a wood and the time when it is finally cut over. It is the first factor affecting the yield. Under clear felling systems it may be an exact and definite period. Under other systems it represents only the average life of each wood in the forest. Under the Selection System it will be the average age at which individual trees reach the diameter or girth required by the objects of management.

Varying types of rotation are recognized, according to the policy to which effect has to be given.

These are :—

(1) The Physical Rotation.
(2) The Silvicultural Rotation.
(3) The Technical Rotation.
(4) The Rotation of the maximum volume production.
(5) The Rotation of the highest income.
(6) The Financial Rotation.

The Physical Rotation is that which coincides with the natural lease of life of the trees.* It is only of importance in park lands and protection forests. The Silvicultural Rotation is the rotation most favourable for natural reproduction. If reproduction is by seed from a shelter wood it may depend not only on the effect of age on the production of a sufficient quantity of fertile seed, but also on the effect produced on the soil conditions by the varying density of the leaf canopy at different ages. For example, with a light-demanding species, unless advantage is taken at an early stage of the production of seed, a growth of weeds may render regeneration very difficult. In the case of coppice the rotation must be below the age at which the trees cease to produce healthy coppice shoots when felled.

The Technical Rotation is that under which the forest yields the most suitable material for a special purpose or results in the production of timber of a size which permits of the most economical conversion.

The Rotation of the Maximum Volume Production is the rotation at which the M.A.I. culminates (*vide* Fig. 1, p. 8). This may be demonstrated as follows:

In a normal series of "r" age gradations of any area, say A acres

Annual yield = Volume of the oldest wood

which by definition = M.A.I. × r ~~per acre~~

annual yield per acre = MAI of oldest wood per acre × r

area felled annually $= \dfrac{A}{r}$ acres

and annual yield therefore $= \dfrac{A}{r} \times$ M.A.I. $\times$ r

$= A \times$ M.A.I. per acre of oldest wood

* Some writers consider (2) as the Physical Rotation.

It follows that the rotation which gives the highest value for the M.A.I. will give the largest volume per acre per annum.

The Rotation of the Highest Income and the Financial Rotation are dealt with later in Part III.

Policy generally demands a consideration of the rotation from several points of view, and, where the objects of management are commercial, this usually results in practice in the adoption of a combination of technical and silvicultural rotation, possibly after the application of a financial test.

VI. The Distribution of Age Gradations or Classes

(Schlich, Vol. III, Part III, Chap. III.)

This distribution varies, of course, according to the type of silvicultural system employed. Silvicultural systems may be classified according as to whether they result in:

(1) Regular forests in which age gradations or classes are recognizable by area.

(2) Irregular forests, in which neither age gradations nor classes are recognizable by area, resulting from natural regeneration over a long period, or over the whole rotation (*e.g.*, the Selection System).

In both cases we have a FELLING SERIES, which may be defined as an area ~~containing~~ or aiming at a normal series of age classes or gradations. It is a Unit of Yield Regulation for management purposes, *i.e.*, a separate calculation of the yield will be made for each series.

(*a*) *Felling Series, Annual Coupes, and Cutting Sections under Clear Felling Systems.*

Under a clear felling system the felling series will consist of a number of ANNUAL COUPES, equal to the number of years in the rotation, differing in age by one year. The area of each will be the total area of the series divided by the number of years in the rotation $= \frac{A}{r}$. *This provides all the regulation of the yield which is required under a system of clear felling in high forest or simple coppice, i.e.*, regulation of the yield is by area only and the annual yield is represented by an annual coupe, the area of which $= \frac{A}{r}$. Coupes, differing in age by

one year, do not, of course, necessarily adjoin one another in practice; they may be distributed in any manner in which silvicultural requirements or convenience demand. There may be a deliberate separation into CUTTING SECTIONS (Schlich's cutting series*)—a subdivision of a felling series formed with the object of regulating the cuttings in some special manner—as for example when insect or fire danger make it necessary that fellings should never take place on adjoining areas at short intervals. Fig. 3 shows diagrammatically 40 annual coupes

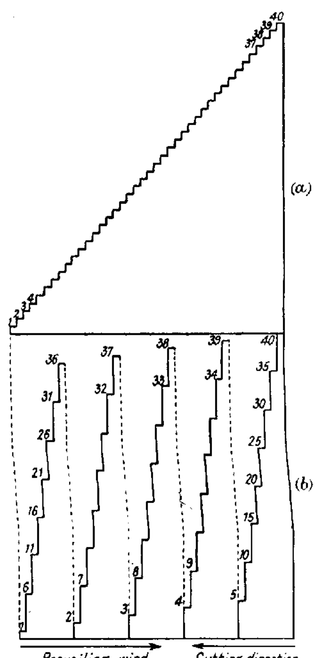


FIG. 3.—(a). UNDIVIDED FELLING SERIES OF 40 AGE GRADATIONS.
(b). FELLING SERIES DIVIDED INTO 5 CUTTING SECTIONS.

* The nomenclature adopted by the Empire Forest Conference of 1928 has been adopted in this book, *vide* Appendix I.

arranged first in one, and then in five cutting sections, the latter providing for a 5-year interval between the felling of two adjoining woods; in the latter case it will be noted that there are $\frac{40}{5} = 8$ age gradations or annual coupes in each cutting section. The above applies to clear felling in high forest with artificial regeneration, and to coppice and, in a slightly modified form, to certain special cases of very rapid natural regeneration under a shelter wood (*vide* Troup's *Silvicultural Systems*, p. 11).

It will be observed that the undivided felling series is preferable from the point of view of protection from wind. Cutting sections are only required where danger from fire, insects, etc., make large felling areas and an unbroken sequence of young woods undesirable, or in order to meet special requirements of management.

(*b*) *Felling Series under Regular Shelter-Wood Systems of Natural Regeneration.*

In a felling series under regular shelter-wood systems of natural regeneration, age classes take the place of age gradations

FIG. 4.—FELLING SERIES UNDER REGULAR SHELTER-WOOD.

and PERIODIC COUPES of annual coupes as in Fig. 4, in which a rotation of 100 years divided into five periodic coupes, or age classes, each containing 20 age gradations, is shown. The distribution of the age gradations within a periodic coupe will depend upon the silvicultural system employed for regeneration, and does not affect management.

The yield is regulated by periods and adjusted as closely as possible for each year by volume only.

(*c*) *Felling Series in Irregular Forests.*

Under silvicultural systems producing irregular forests the age gradations—though indistinguishable by area—may be assumed to be present in any unit of yield regulation, and the

term "Felling Series" may therefore be applied to such unit.

In a small selection forest the whole area may be worked over every year, and will then represent a complete and undivided felling series. This, however, is unusual, and the general custom is to divide the area into parts, each of which shall be worked over at an interval of years known as the FELLING CYCLE (the interval elapsing between two principal fellings under the selection system*). The number of these parts will obviously be equal to the number of years in the felling cycle; they may be compartments (*vide* next section) or collections of compartments. In the latter case they will be cutting sections. Fig. 5 depicts a forest on a rotation of 96

I Felled in years 1, 7, 13, 19, 25, 31, 37, 43, 49, 55, 61, 67, 73, 79, 85, 91.	*II* Felled in years 2, 8, etc. to 92.	*III* Felled in years 3, 9, etc. to 93.
IV Felled in years 4, 10, etc. to 94.	*V* Felled in years 5, 11, etc. to 95.	*VI* Felled in years 6, 12, etc. to 96.

FIG. 5.—FELLING SERIES IN SELECTION FOREST.

years with a felling cycle of 6 years, and 6 compartments or cutting sections, in each of which 16 (*i.e.*, $\frac{96}{6}$) annual fellings will be carried out. There will be no annual coupes recognizable by area, *and the yield can only be regulated, if at all, by prescribing the number of trees or volume to be felled.* In theory age gradations follow annual fellings; in practice, since regeneration is continuous, they will probably be distributed over the series.

(d) The Felling Series under the Coppice with Standards System.

In coppice with standards the arrangement of the age gradations in the overwood is the same as in theory exists in selection high forest, regarding each annual coupe as a cutting section, except that the age class, 0 to r (rotation of coppice) is missing,

* Felling Cycle is sometimes used to describe the interval between the principal fellings under other systems.

being included in the underwood. The age gradations in the underwood are arranged as in clear felling high forest. The rotation of the overwood (R) must be a multiple of the rotation of the underwood. Fig. 6 represents a coppice with standards felling series, where r = 10 and R = 40, immediately prior to the felling of the tenth annual coupe. ~~The yield of the over-wood~~ will depend on the number of standards of each age which it is desired to retain when felling each coupe. Thus

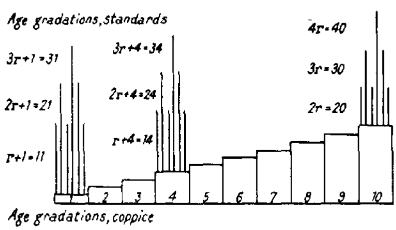


FIG. 6.—FELLING SERIES UNDER COPPICE WITH STANDARDS.

if these are " a " aged r years, " b " aged 2r years, " c " aged 3r years :—Then the number felled each year will be

a – b aged 2r years, b – c aged 3r years ; and c aged 4r years.

For example if the ~~numbers~~ are 100, 60, 30. Then when the coppice is felled 100 trees will be left to grow into standards and the annual yield in standards, if there are no intervening ~~casualties, will be 100~~ – 60 = 40 aged 2r years

60 – 30 = 30 aged 3r years

30 aged 4r years.

The yield, therefore, of the overwood is regulated by the number of trees, whilst that of the underwood is by area.

VII. The Compartment

Under all systems of management for a sustained yield, with the exception of very small forests worked under the selection system, some division of the area is necessary if only for the purpose of locating the crop. COMPARTMENTS, with either natural features or artificial lines as boundaries, are the

smallest permanent units of area with which management is concerned.

Ideally they form silvicultural units suitable for the purpose of making a descriptive inventory of the crop and for prescribing the details of management. If they do not fulfil these conditions, temporary sub-compartments may have to be formed.

The degree to which a compartment must conform to the above conditions will depend on the intensity of management, and the importance of the position occupied by the compartment varies greatly under different conditions and systems of management. Obviously the smaller the compartments the easier it will be to make them homogeneous. If the yield is regulated by volume and not area, homegeneity is unimportant and may be impossible. Under the Selection System a single compartment will probably contain representatives of all age gradations; it is therefore a management unit only and will tend to be larger than under other systems where compartments may fulfil the purpose of differentiating crops of various ages.

Under coppice, and high forest clear felling systems, management will be facilitated if compartments contain only one annual coupe.

Under a shelter-wood system the ideal compartment will contain no more age gradations than are equivalent to the number of years in a regeneration period, except in so far as irregularities have been introduced by subsequent beating up and underplanting. Natural regeneration, however, is not always obtained with the regularity postulated by theory, and at the end of a working-plan period regeneration may have been completed in one part of a compartment and hardly commenced in another part. In such circumstances, if management requires age classes to be defined by area, the correct procedure is to form two sub-compartments. Sub-compartments are temporary divisions and can be abandoned later, for with advancing age the two crops will level up and will probably not require different treatment.

To sum up :—A compartment is primarily a unit of management; if it can be made to serve the purpose of a silvicultural unit as well, so much the better; but, as it is a permanent unit, its boundaries should not be altered to suit conditions, which may be transitory, such conditions being met by the formation of sub-compartments.

VIII. Quality of Locality

Under silvicultural systems, in which age gradations or classes are recognizable by area, each gradation or class should (for the purpose of yield regulation) occupy areas of equal productivity rather than of equal extent. Management, therefore, requires that, before the distribution of areas for the regulation of the yield takes place, the productivity (quality) of the smallest units of management (compartments) should be assessed. The methods of doing this will have been learnt under silviculture and mensuration. For the purpose of application it is usual to assess each quality class in decimals according to a standard quality. The figure by which each class must be multiplied to reduce it to the standard is known as the REDUCING FACTOR and the area so obtained as the REDUCED AREA. Thus :—

Quality Class.	*Yield per acre at Maturity in c. feet.*	*Reducing Factor.*	10 *acres real area becomes in Reduced Area.*
			Acres.
I	6,000	$\frac{6,000}{5,000} = 1·2$	$10 \times 1·2 = 12·0$
II *Standard*	5,000	$= 1·0$	$10 \times 1·0 = 10·0$
III	3,500	$\frac{3,500}{5,000} = 0·7$	$10 \times 0·7 = 7·0$

CHAPTER II

The Relations between the Normal Growing Stock, Increment and Yield

I. Normal Age Gradations and Growing Stock

Since every wood represents the sum of the annual increments laid on up to date by that wood, a normal series of age

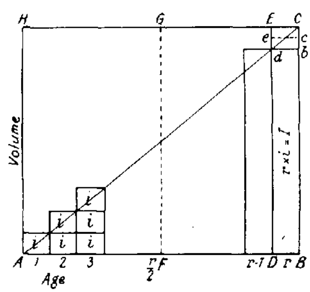


FIG. 7.—RELATIONS BETWEEN INCREMENT AND GROWING STOCK.

gradations may be represented as in Fig. 7, where the base line AB represents units of area, each occupied by a wood differing by one year from the preceding, and the volumes standing on these areas are represented by a number of equal rectangles each equivalent to one year's increment. Thus, if the annual increment in each wood be represented by the rectangle i, the volumes of each age gradation will be represented by i, 2i, 3i, . . . ri. The total growing stock represented in this manner will be that for the autumn or end of the growing season before the oldest wood has been felled. This method of illustrating the growing stock may, of course, be applied whether the age gradations occupy separate areas or are scattered over the

forest, also where age classes, representing several age gradations thrown together, are dealt with, the age of the class in this case being considered as the mean age.

The above assertions are based on the assumption that the current annual increment of each wood is throughout equal to the final mean annual increment, or in other words that a wood lays on an equal volume each year throughout the rotation. This, of course, is incorrect, and this fact must be borne in mind when using this method for calculating volumes, as is explained later in Section III.

II. Age Gradations and Increment

See Fig. 7. r × i is often represented by I, and I or r × i

= (*a*) Volume of oldest age gradation in the autumn.

Also = (*b*) Final mean annual increment of any one age gradation × rotation.

Also = (*c*) Current annual increment of all age gradations, or in other words

= (*d*) Mean annual increment of the series.

It is clear, therefore, that in a normal forest either (*a*), (*b*), (*c*) or (*d*) will represent the normal yield.

III. The Volume of the Growing Stock from the Mean Annual Increment (Schlich, Vol. III, p. 217.)

Required to ascertain the volume of the growing stock of a series from *I*, generally called in this case the *Mean Annual Increment.* It has been shown in Fig. 7 that the rectangles i, 2i, 3i, . . . ri represent the autumn growing stock of each age gradation. Let us now consider what the volume of the G.S. will be half-way through the growing season, or the volume of the summer growing stock as it is called.

Taking the oldest age class, the whole increment for the year is represented by the ▭ EdbC. If the increment be divided into two equal parts by the line ec then the volume of the oldest age class in the summer = ▭ eDBc, which = figure CBDd (since △ Cbd = ▭ edbc).

A similar proposition can be proved for each of the other age gradations, so that finally we find the summer G.S. of the series is represented by the △ ABC.

Dividing the rotation into two equal parts at F it is clear that the

$\triangle$ ABC, representing the *Summer* G.S. $= \square$ GFBC $= I \times \frac{r}{2}$.

In the autumn, immediately before the oldest wood is felled, the G.S. will be represented by the full rectangles, and therefore to the $\triangle$ ABC must be added the $\triangle$'s above the diagonal, *i.e.*, $\frac{i}{2} \times r$ or $\frac{I}{2}$

i.e., the *Autumn G.S.* $= \left(I \times \frac{r}{2}\right) + \frac{I}{2}$.

In the spring, when the oldest wood has been felled and no further growth has yet taken place, I must be deducted from the autumn G.S.

$$\textit{Spring}\ \text{G.S.} = \left(I \times \frac{r}{2}\right) - \frac{I}{2}.$$

For practical purposes the simpler formula for the summer is generally used.

The accuracy of the above formulæ is affected by the considerations pointed out in the last paragraph of Section I.

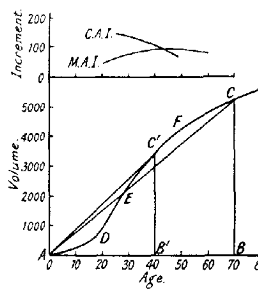


FIG. 8.—YIELD TABLE G.S. COMPARED WITH G.S. OBTAINED FROM FINAL M.A.I.

This fact is illustrated in Fig. 8, where the curve ADEFC represents the evolution of the volume from O upwards, as obtained from a yield table, and it is clear that the volume of the G.S. is represented by the area ADEFCB and not by the

area ABC. At the age of 70 these areas are approximately equal, owing to the approximate equality of the areas ADE and EFC. But, if we take a 40-year rotation, it is clear that the true normal G.S. will be considerably less than the G.S. represented by the $\triangle$ AB′C′. It is also easy to see that the nearer the rotation is to the time at which the growth of the wood is most active, *i.e.*, to the time at which the C.A.I. culminates, the greater will be the volume of "I" (the oldest age class) compared to the volume of the real G.S.

The volume of the true normal G.S. will not attain equality with that obtained from the formula G.S. $= \text{I} \times \frac{r}{2}$ until some considerable time after the C.A.I. has fallen below the final M.A.I., *i.e.*, until after the M.A.I. has reached its maximum, *i.e.*, *until beyond the Rotation of the greatest Volume Production* (*vide* Chap. I, Section III). Since it is seldom economical to work with longer rotations than this, and since the general tendency in Europe is to work with shorter ones, this matter is of considerable importance. This has led Flury (Swiss Forest Service) to suggest the substitution of a constant "c" for $\frac{1}{2}$ in the above mid-season formula, *i.e.*, for $\frac{r}{2}$ read cr.*

For example:

	Rotation			
	60	80	100	120
Value of "c" for s. pine in N. Germany	0·387	0·454	0·503	0·508

It is apparent from the above and also from Fig. 8 that, after equality has been attained, for longer rotations the formula G.S. $= \text{I} + \frac{r}{2}$ will give a volume less than that of the true normal, G.S.

IV. Yield in Terms of Growing Stock, and Distribution of Increment to Old and New Growing Stock

Accepting Fig. 7 as correctly representing the growing stock, the following will hold good:

(*a*) The yield during a rotation = twice the growing stock, and

* *Vide* Recknagel, *Forest Working Plans*, p. 7.

(*b*) During a rotation, half the increment is felled during that rotation, and the other half goes to the new G.S.

Proof of (*a*), *vide* Fig. 7.

$$\text{Yield in 1 year} = \square\,\text{EDBC}$$
$$\begin{aligned}\text{Yield in rotation} = \text{r} \times \square\,\text{EDBC} &= \square\,\text{HABC} \\ &= 2\,\triangle\text{ABC} \\ &= 2\ \text{G.S.}\end{aligned}$$

The formula derived from this,

$$\text{annual yield} = \frac{2\ \text{G.S.}}{\text{r}}$$

is known as Von Mantel's Formula and is one much used in yield regulation.

Proof of (*b*). Now it has already been proved (Section 3)

$$\text{that G.S.} = \text{I} \times \frac{\text{r}}{2},$$

where I = 1 year's increment laid on over the whole forest: so that, since yield = 2 G.S. = G.S. + G.S.,

$$\begin{aligned}\text{Therefore yield} &= \text{G.S.} + \left(\text{I} \times \frac{\text{r}}{2}\right) \\ &= \text{G.S.} + \tfrac{1}{2}\ \text{increment during a rotation,}\end{aligned}$$

the other half of the increment going to the new G.S. Or in other words, during a rotation half the yield is represented by the growing stock at the commencement of the rotation and half the increment during the rotation.

V. *To Ascertain the Volume of the Growing Stock from Yield Tables*

As these give volumes not year by year but only at intervals of several years it is necessary to fill in the volumes for intervening years on the assumption that the increment is laid on in equal quantities annually during these periods. This introduces an error of the same nature as that which arises in calculating the G.S. from the M.A.I., but, owing to the short periods involved, it is not in this case of practical importance.

See Fig. 9. Assume a yield table showing 4 entries only at intervals of n years, the volumes in the n^{th}, $2n^{th}$, $3n^{th}$ and $4n^{th}$ years being represented by the rectangles A, B, C and D.

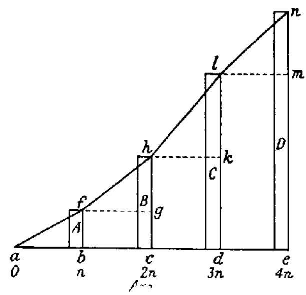


FIG. 9.—VOLUME OF G.S. FROM YIELD TABLE.

The total volume of the summer growing stock, for the rotation r (= 4n) on r acres, will be the sum of the figures abf, fbch, hcdl and lden

$$\text{abf} = A \times \frac{n}{2}$$

$$\text{fbch} = \square\,\text{fbcg} + \Delta\,\text{fgh} = nA + (B - A)\frac{n}{2}$$

$$\text{hcdl} = \square\,\text{hcdk} + \Delta\text{hkl} = nB + (C - B)\frac{n}{2}$$

$$\text{lden} = \square\text{ldem} + \Delta\text{lmn} = nC + (D - C)\frac{n}{2}$$

so that

$$\text{G.S.} = \left\{A \times \frac{n}{2}\right\} + \left\{nA + (B - A)\frac{n}{2}\right\} + \left\{nB + (C - B)\frac{n}{2}\right\} + \left\{nC + (D - C)\frac{n}{2}\right\}$$

$$= \frac{nA}{2} + nA + \frac{nB}{2} - \frac{nA}{2} + nB + \frac{nC}{2} - \frac{nB}{2} + nC + \frac{nD}{2} - \frac{nC}{2}$$

By cancellation

$$= n\,(A + B + C + \frac{D}{2})$$

For the sake of convenience only 4 values have been taken in the above, but the formula is clearly correct if written

$$G.S. = n(V_n + V_{2n} + V_{3n} + \ldots V_{r-n} + \frac{V_r}{2})$$

As shown in Section III, for the autumn and spring it will be

$$n\left(A + B + C + \frac{D}{2}\right) + \frac{D}{2}$$

$$\text{and } n\left(A + B + C + \frac{D}{2}\right) - \frac{D}{2} \text{ respectively.*}$$

It is clear that the volume of the G.S. can also be ascertained by counting up the squares or by drawing Fig. 9 on sectional paper and the use of a planimeter, but, if this process is used, it is preferable to draw a volume curve with the ages and volumes as abscissæ and ordinates respectively as in Fig. 10.

In using a yield table to ascertain the volume of the G.S. in a forest it must be remembered that the volume obtained from the yield table by one of the above methods is the volume on as many acres as there are age gradations.

* The formula can also be evolved arithmetically on the basis that two consecutive entries in a yield table represent the first and last terms of an arithmetical progression. The number of terms in each series will be n + 1. After summing the series, and deducting the values included twice, the result will be the autumn G.S. Thus:

$$G.S. = (V_0 + V_n)\frac{n+1}{2} + (V_n + V_{2n})\frac{n+1}{2} + \ldots (V_{r-n} + V_r)\frac{n+1}{2}$$
$$- (V_n + V_{2n} + \ldots V_{r-n})$$
$$= \frac{n+1}{2}(V_0 + 2V_n + 2V_{2n} + \ldots 2V_{r-n} + V_r) - (V_n + V_{2n} + \ldots V_{r-n})$$
$$= (n+1)(V_n + V_{2n} + \ldots V_{r-n} + \frac{V_r}{2}) - (V_n + V_{2n} + \ldots V_{r-n})$$
$$= n\left(V_n + V_{2n} \ldots V_{r-n} + \frac{V_r}{2}\right) + \frac{V_r}{2}$$

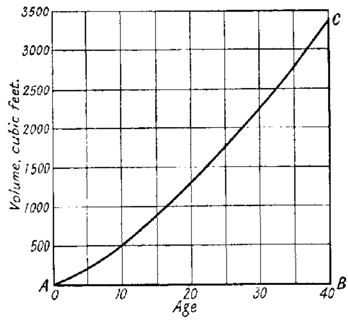


FIG. 10.—GRAPHIC DETERMINATION OF VOLUME OF G.S. FROM A YIELD TABLE.

YIELD TABLE.

Age.	*Volume.*
10	500
20	1370
30	2280
40	3380

SCALE.

Abscissæ $\frac{1}{20}''$ = 1 year.
Ordinates $\frac{1}{20}''$ = 100 c.f.
1 sq. in. = 40,000 c.f.

Area of ABC = 1·43 sq. ins.
= 57,200 c.f.
= Volume on 40 acres.

By Formula—

$$\text{Volume} = 10\left(500 + 1370 + 2280 + \tfrac{3380}{2}\right)$$
$$= 58{,}400 \text{ c.f.}$$

Example: Required the volume of a forest of 1,200 acres containing age gradations 0 to 50 equally represented and fully stocked, to which the following yield table applies:

Age.	*Volume (cu. ft.).*
10	460
20	1400
30	2800
40	4400
50	6200

Summer volume on 50 acres $= 10\left(460 + 1{,}400 + 2{,}800 + 4{,}400 + \frac{6{,}200}{2}\right) = 121{,}600$

$$\text{Volume on } 1{,}200 \text{ acres} = \frac{121{,}600 \times 1{,}200}{50} = 2{,}918{,}400 \text{ cu. ft.}$$

If determined from the formula $I \times \frac{r}{2}$;

$$\text{Volume} = 6{,}200 \times \frac{50}{2} \times \frac{1{,}200}{50} = 3{,}720{,}000 \text{ cu. ft.}$$

Yield tables give volumes per unit acre for fully stocked areas. In practice, woods are seldom, if ever, found to be fully stocked and, in order that a yield table may be correctly applied to determine the volume of any wood, the density of that wood compared with a fully stocked wood must first be assessed. It is usual to consider the density of a fully stocked wood to be represented by 1·0 and to represent the density of a real wood by decimals. Thus in the above example, if the density of the 50-years-old wood was represented by ·8 the volume per acre would be 6,200 × ·8 = 4,960. ·8 is a reducing factor for density and must not be confused with the reducing factor for quality (p. 20). The former relates to a condition (possibly temporary) of the crop, whilst the latter relates to a more or less permanent condition of the locality. The assessment of density is dealt with under Mensuration.

CHAPTER III

Silvicultural Systems in Relation to Yield Regulation

The continent of Europe was the birth-place of scientific forestry and therefore most methods of yield regulation and calculation originated there. These methods were generally discovered and applied in the first instance by local foresters, and were designed to suit local conditions. Thus it usually happened that a method of yield regulation became associated with a particular method of management (in the broad sense), and silvicultural system. To maintain any such strict association in studying the principles of Forest Management and methods of yield regulation and calculation would, however, lead to confusion of mind and suggest the idea that Forest Management consists in adopting a recognized combination of silvicultural system, yield regulation and calculation, designed for one locality, and applying it to another locality.

Such an idea of Forest Management is altogether erroneous, and particularly dangerous to a forester dealing with conditions so diverse as obtain in the British Empire, conditions also which are generally so different from those found on the European continent. The student of Forest Management can only be instructed in the principles and given examples of their application. The knowledge thus acquired can be used only to provide material from which the forester may select in building up his own scheme of silviculture and management in the forest for which he is responsible.

Some methods of yield regulation imply a certain method of yield calculation, and some methods of yield regulation or calculation are particularly applicable to, or even in some cases only applicable to, certain types of silvicultural systems. It will be the endeavour here to explain these cases of limited applicability whilst treating the subjects of yield regulation and calculation as a separate and special branch of management.

For the purpose of considering the effect of silvicultural systems on yield regulation it is only necessary to recognize 3 types of the former, namely :—

A. Clear Felling, resulting in Regular Forests in which age gradations are recognizable by area.
B. Regular Shelter-Wood systems, resulting in Regular Forests in which age classes are recognizable by area.
C. Irregular Shelter-Wood systems, resulting in Irregular Forests in which neither age classes nor age gradations are recognizable by area.

In Type A, as explained in Chapter I, Section VI, yield is regulated by annual coupes equal in area. The volume of the annual yield will be known from past experience. We have now, therefore, only to deal with the conditions found in B and C.

CHAPTER IV

Yield Regulation in Regular Forests

I. Classification of Methods

Generally speaking, yield regulation is for final fellings only, thinnings being considered purely silvicultural operations, the annual incidence of which it is impossible to restrict by imposing a fixed yield.

There are two ways of approaching the subject of the regulation and determination of the yield:

(*a*) Yield regulation based primarily on division of the area.
(*b*) Yield regulation based primarily on the volume and increment of the whole growing stock.

(*a*) *Yield regulation based primarily on a division of the area.*

Since in Type B forests, referred to in Chapter III, age classes are recognizable by area, it is possible to regulate the yield by distributing the woods to periods of the rotation according to their present age and condition. This distribution may be complete so that each period has the necessary woods allotted to it (Periodic Block), or on the other hand it may be considered sufficient to select those woods which will require to be regenerated during the 1st period only, leading to the formation of a Floating Periodic Block (French Quartier Bleu), the location of which will necessarily change at each revision of the Working Plan. The periods elapsing between these revisions are under such circumstances often as short as 10 years and will seldom exceed 20 years. The annual yield during the currency of the working plan is, in both cases, generally determined from the volume standing in the block under regeneration only. The methods used are described in detail in Sections II, III and IV of this chapter.

(*b*) *Yield regulation based primarily on the volume and increment of the whole G.S.*

The annual yield or the yield for a limited period of years is determined by means of a formula from the whole growing

stock, or the increment of the same, or from both. Woods are then selected in which regeneration fellings will be required during the period of the plan and the yield as calculated above is cut therein.

Whilst from the silvicultural point of view the Floating Periodic Block under (*a*) is the same as the Floating Regeneration Area under (*b*), from the management point of view the former is a unit for the calculation of the yield and the latter is not, and, whereas the former is only applicable in cases where the forests have been under scientific management for a long time and are therefore approaching normal, the latter can be applied to other conditions. Thus Troup (*Silvicultural Systems*, p. 58) advocates the application of the Floating P.B. system to Sal Forests in India where silviculture requires that fellings should follow rather than precede regeneration. From the management point of view this system would be more properly considered under (*b*) than (*a*); since, assuming that the establishment of the normal forest is being seriously attempted, the Floating P.B., formed for silvicultural reasons only in an abnormal forest, would not by itself provide a unit for accurate yield control.

The methods in use are dealt with in Sections V to IX of this chapter.

II. Allotment of Woods to Periods of the Rotation with Determination of the Annual Yield from the Current Period only.

The rotation is divided into a convenient number of periods. The length of a period is generally based on the length of time which it is anticipated it will take to regenerate. Where regeneration is an easy and almost mechanical process this may be the same as the period elapsing between the first and the final regeneration fellings in any one place. The areas into which the forest is divided by the periods are known as PERIODIC BLOCKS. The approximate area of a periodic block is found from the formula, area $= \frac{S \times P}{R}$ where S = total area of the series, P = number of years in a period and R = Rotation. The periodic blocks may be either self-contained or made up of compartments taken from anywhere in the

series according to their silvicultural requirements. Compartments are generally allotted so that the areas in each block are approximately equal or equi-productive. Equi-productivity of the blocks can be obtained to a sufficient degree by calculating the reduced areas of compartments (Chapter I, Section VIII) and allotting equal reduced, instead of equal real areas to each period.*

Reduced areas having been calculated, compartments will, in the first instance, be allotted to the periods according to their condition, the ripest being allotted to Period I and so on. Unless the forest is in a normal condition, this initial allotment will result in an unequal distribution, and therefore shiftings will be made resulting, to a certain extent, in the sacrifice of silvicultural requirements and maximum yield to the equalization of returns. If all goes according to plan the forest will, in theory, be in a normal condition after one rotation.

Example: Rotation 80 years, 4 periods of 20 years each. Forest divided into 10 compartments as follows:

Compartment.	*Present Mean Age.*	*Reduced Area.*
1	25	5
2	70	3
3	60	3
4	10	4
5	30	3
6	80	6
7	50	5
8	45	3
9	70	4
10	10	7
	Total ...	43 acres

In this example only two compartments, *i.e.*, 2 and 8, have had to be shifted to obtain the maximum possible equalization of the area. In practice, of course, not only the mean age but also the

* Hartig (*vide* Schlich, Vol. III) calculates the final volume of each compartment at maturity, and allots compartments to the periods so as to obtain approximately equal volumes in each period. As the method has very limited application it is not dealt with here.

ALLOTMENT OF COMPARTMENTS TO PERIODS.

Compt.	*Present Mean Age.*	*Initial Allotment to periods.*				*Final Allotment to periods.*				
		I 1–20 yrs.	II 21–40 years.	III 41–60 years.	IV 61–80 years.	I	II	III	IV	*Average age when felled.*
1	25	—	—	5	—	—	—	5	—	75
2	70	3	—	—	—	—	3	—	—	100
3	60	—	3	—	—	—	3	—	—	90
4	10	—	—	—	4	—	—	—	4	80
5	30	—	—	3	—	—	—	3	—	80
6	80	6	—	—	—	6	—	—	—	90
7	50	—	5	—	—	—	5	—	—	80
8	45	—	3	—	—	—	—	3	—	95
9	70	4	—	—	—	4	—	—	—	80
10	10	—	—	—	7	—	—	—	7	80
Total ...	...	13	11	8	11	10	11	11	11	
Average age of woods felled in each period ...					...	86	88	82	80	

general condition of the compartments, such as vigour of growth, presence of advance growth, etc., would be considered.

The annual yield during the 1st period of 20 years would be ascertained by measuring the volume standing in P.B.I., *i.e.*, Compts. 6 and 9, adding the increment for 10 years (the *average length* of time the trees will be left standing), and dividing by 20,

i.e., annual yield $= \dfrac{V + \frac{I}{2}}{20}$ *

Alternatively, the volume may be determined direct from a suitable yield table if available; in this case obviously nothing will have to be added for increment. Assuming that in the above example the real areas of compartments 6 and 9 are 8 and 5 acres, and their densities ·7 and ·9 respectively, and that the appropriate yield table for compt. 6 gives a volume of 6,500 cubic feet at 90 years and for compt. 9 volume of 6,000 cubic feet at 80 years, then the annual yield

$$= \frac{(6{,}500 \times 8 \times \cdot 7) + (6{,}000 \times 5 \times \cdot 9)}{20}$$

Forests are occasionally found where regeneration is obtained with such facility that its completion in any compartment allotted to a period can be counted on within that period; but, as this is seldom the case, one of two alternative situations will arise according to whether the division into periodic blocks is a permanent one, or one liable to revision at each revision of the Working Plan.

If it is permanent the position will be that in addition to the fellings to be prescribed in the P.B. next in order of working, the removal of the balance of the overwood in certain compartments of the P.B. just worked over must be arranged. The volume of the latter (and its estimated increment before felling) will have to be added to the volume of the former to obtain the yield. But, since the same position is likely to arise again at

* Failure to make allowance for increment will result in theory in a continual increase in the yield at each revision without ever attaining the yield available. Deliberate omission of the increment is a common feature of French management, with the idea of maintaining a reserve against eventualities. The French are essentially a safety-first nation in matters affecting investments or material security. A student of forestry in order to appreciate correctly the lessons to be learnt from foreign systems of management should consider how they are affected by the special circumstances and character of the persons concerned.

the end of each period, a deduction from the yield thus obtained will have to be made for the same reason : thus if

V_1 = Volume and estimated increment before felling of the overwood remaining in P.B.I at the end of the period.
G = Volume standing plus increment in P.B.II and
V_2 = Estimated volume of the overwood which will remain in P.B.II at the end of Period II.

Then annual yield during Period II $= \frac{V_1 + G - V_2}{20}$. In many cases, however, sufficient accuracy will be obtained by assuming that the remaining overwood is the same at the end of each period, in which case V_1 and V_2 cancel one another and the yield can be ascertained from the volume of the current P.B. only, as shown in the above example.

If the allotment of compartments to P.B's is not permanent, then the normal procedure will be to allot in the first instance to the current P.B. those compartments in which regeneration has already been commenced. If the normal area only is at the same time allotted to the current P.B., it is clear that the full yield will not be cut, and, since some compartments will be allotted to two consecutive periods, the forest will not be worked over in a rotation. It will, therefore, be necessary always to allot a larger area to the current P.B. proportionate to the reduced density of the growing stock in some of its compartments, as shown in the following example :

Area of forest = ~~2,000~~ 310 acres, rotation = 100 years, period = 25 years, normal area of P.B. = 80 acres, average volume of wood standing on 1 acre of mature forest = 6,000 cu. ft.

CONSTITUTION OF CURRENT REGENERATION BLOCK.

Compt. No.	*Real area.*	*Volume per acre.*	*Reducing factor.*	*Reduced area.*
(*a*) Compartments in which regeneration fellings have already been commenced.				
3	40	1500	$\frac{1500}{6000} = \cdot 25$	10
5	24	4500	$\frac{4500}{6000} = \cdot 75$	18

(b) Compartments in which regeneration fellings have not been commenced.

Compt. No.	*Real area.*	*Volume per acre.*	*Reducing factor.*	*Reduced area.*
6	25	6000	1	25
9	27	6000	1	27
Total ...	116			80

Under the above Periodic Block method it will be seen that regeneration fellings are confined to one P.B. (with perhaps the removal of the remaining overwood in same compartments of another), whilst the operations in the remaining blocks will be of the same nature in all, *i.e.*, thinnings. The necessity for allotting all compartments to periods has therefore been questioned, and it is also objected that it is impossible to foresee the requirements of any area in the distant future. These considerations lead the French to distinguish another method —*Futaie régulière à affectation unique*, *i.e.*, the SINGLE PERIODIC BLOCK method—under which woods are allotted to the current regeneration block only. It will be noted that the regulation of the yield is still based on a periodic block of fixed area, which distinguishes this method from the floating periodic block method dealt with in the next section. Where scientific management has not been sufficiently long in operation to ensure that the forest approaches a normal condition, it is advisable, however, that the officer responsible for the Working Plan should, if conditions permit, make a tentative allotment to all periods in order to indicate the extent to which it has been possible to provide in theory for future requirements. The extra labour involved in making the distribution will be inconsiderable provided that a thorough inspection of each compartment has been made.

In modern practice permanent P.B's are generally avoided except where rapid regeneration can be counted on and the forest is not endangered by destructive agencies.

III. The Floating Periodic Block

Where forests have, as a result of a long period of management under the P.B. system, attained a sufficient approach to normality, there is little objection from the point of view of the

regulation of the yield to the allotment to the current period only of compartments which require to be regenerated, since these will form more or less the correct proportion of the whole. The floating P.B. system is thus a development of the fixed P.B. system, the various steps in development being as follows:

Fixed self-contained P.B's with permanent boundaries.
Fixed scattered P.B's with permanent boundaries.
P.B's scattered or self-contained with boundaries subject to revision at intervals.
Floating P.B. passing gradually over the whole forest.

Each step aimed at greater elasticity and freedom to select woods for regeneration according to silvicultural requirements. In considering the future of forests not yet under scientific management it is not necessary to assume that all steps will be passed through.

The Floating P.B. system has been developed in France under the name of Quartier Bleu Method* since the Floating P.B. is coloured blue on the map; the remainder of the area which is treated by thinnings is left uncoloured and called the Quartier Blanc. At each Working Plan revision compartments are allotted to the Quartier Bleu as follows:

Group I. Those which are already under regeneration.
Group II. Those which should come under regeneration during the Working Plan period.

The yield during the Working Plan period is ascertained from the volume of each compartment allotted to the Quartier Bleu. The method of determining the annual yield varies, but is usually based on the length of time which it is anticipated it will take to regenerate each compartment.

The Working Plan period is any convenient time and generally has no special relation to a Regeneration period. Often it is fixed by the Thinning Cycle, *i.e.*, if thinnings are carried out every 10 years the Working Plan may be for 10, 20 or 30 years. *Thus there is no Period which must be a sub-multiple of the rotation, as in the Fixed P.B. system.*

* The method here described is Q.B. as usually applied to regular forests. The French apply the term Q.B. also to the current regeneration block in an irregular forest where the method is, of course, quite different—*vide* Chap. V, Section III.

Duchaufour devised a method of calculating the annual yield particularly applicable to the Quartier Bleu (Q.B.) method of yield regulation. It is as follows :

He uses the formula :

Period of Exploitation : area of compartments in Q.B. : : Rotation : Total Area

$$X : c : : R : S$$

$$\text{or } \frac{X}{C} = \frac{R}{S} \text{ and } X = \frac{C}{S} \times R$$

N.B.—This is the same formula as that which gives the area of a P.B. under the fixed P.B. method ; but in that case c, the area of the P.B., is the unknown factor and the formula becomes $c = \frac{S \times X}{R}$ (*vide* p. 33).

The area c is ascertained by adding the full area of Group II compartments to the reduced area of Group I compartments. The reduced area here means the area reduced in accordance with the density of the crop, since final fellings have already commenced. The Group II forests are the standard for density purposes and represent 1·0 or fully-stocked woods.

The reduced area of Group I, say C_1, is ascertained from the formula $C_1 = K^2g^2n$ or K^2d^2n

where g = mean girth of the trees in Group I.
,, d = mean diameter of the trees in Group I.
,, n = number of trees in Group I.

K is a coefficient by which the girth (or diameter) of the mean tree must be multiplied in order to obtain the side of the square occupied by the crown.

Thus K^2g^2 gives the area occupied by the mean tree and K^2g^2n gives the reduced area of the compartments in Group I in terms of a fully stocked wood in Group II.

The value of X having been ascertained as above, the annual yield is determined by dividing the total volume standing on the Quartier Bleu by this value. An allowance for increment may or may not be added.

The forest is divided into a large number of Felling Series, for each of which a separate calculation of the yield is made.

Example (from the Forest of Retz)

FELLING SERIES NO. 5.

Inventory and calculation of the Annual Yield.
Area 1324·39 hectares. Rotation 150 years.

GROUP I.

Compt.	*Reduced area in hectares.*	*Species.*	*Number of Trees.*	*Total Volume Cubic Metres*
4	3·46	Oak Beech Various	236 1311 114	1651
etc.	etc.			etc.
Total ...	23·03			10,741

GROUP II.

Total ...	*Actual Area* 163·95			44,369
Total Groups I and II	186·98			55,110

$$\text{Length of X} = \frac{150 \times 186{\cdot}98}{1324{\cdot}39} = 21 \text{ years.}$$

$$\text{Annual yield} = \frac{55110}{21} \text{ cubic metres.}$$

N.B.—No allowance for increment.

Considerable interest attaches to the method of ascertaining the value of K. It is as follows:

A convenient area, say 500 × 500 metres is measured in Group II, considered for practical purposes as fully stocked.

The trees are enumerated and measured:

Let n = number of trees.
,, g = mean girth.
,, D = average side of square occupied by their crowns.

Then D is ascertained from the formula

$$nD^2 = 500 \times 500$$

and K from the formula Kg = D.

Note.—In the forest of Retz, where beech greatly predominates, Kg = D and K = 5. In Compiègne, where there is more oak, the formula Kd = D is used, *i.e.*, the diameter is substituted for girth, K = 16.

Duchaufour's method takes into account, in theory at least, every correct principle of yield regulation whilst allowing no interference by management in the carrying out of silvicultural requirements. The following points may be noticed:

(1). A convenient period for the currency of the special Working Plan having been selected, woods, which will require a completion or commencement of regeneration fellings during that period, are allotted to the Q.B. (silviculture).

(2). No period is laid down for the completion of regeneration anywhere; but the method of calculating X ensures that the condition of the crops shall govern the speed of regeneration fellings, for the more open they are the shorter the length of X; also, since X bears the same relation to the Rotation as the area of the Q.B. does to the whole area, the regeneration of the whole during the rotation is provided for (Yield regulation and silviculture).

Moreover, since the woods in one Felling Series are practically similar in quality, age, and density, and, since the Group I woods are merely Group II woods opened out after attaining their principal height growth, volumes are approximately in proportion to area; so that the length of X will vary in accordance with the volume to be removed.

It may be asked what would happen if:—

(*a*) X worked out to less than the Working Plan period.

(*b*) Before the end of the Working Plan period it was found silviculturally impossible to obtain the calculated yield in the Q.B.

The French do not contemplate such situations arising in the forests in question, but, should they do so, the following would appear to be the correct ways to deal with them. As regards (*a*), the W.P. period is arbitrary and could therefore be reduced, or alternatively more compartments could be added to the

Q.B. As regards (*b*), this might happen if regeneration operations were delayed through unforeseen circumstances such as failure of seed years, fire, etc., or again it might happen on account of an under-estimate of the normal period required to regenerate. Both causes would indicate a revision of the W.P. ~~and~~ a temporary reduction in the yield (lengthening of X) ~~On the other hand, if the position were as described under (*b*) then the situation would be dealt with~~ and by an increasi~~ng~~e the proportion of the Q.B. to the whole area. This would involve a temporary suspension or reduction of the fellings.

An example of the kind of silvicultural mistake which would result in the latter situation would be provided by an attempt to apply the silvicultural system and short regeneration period suitable for the mixed beech and oak forests dealt with above to the mixed beech and fir forests in the Vosges, the systems of management for which are dealt with in Chapter V, Section III.

*IV. Judeich's Method**

Long before the method of the Floating Periodic Block had been developed in France, Judeich had worked on the same principle in Germany. His method was briefly as follows :—

(1). Selection of mature and other woods which require to be felled for silvicultural reasons during a short W.P. period (usually 10 years).

(2). A comparison of the area thus obtained with the normal coupe for the period; *i.e.*, with Total Area $\times \dfrac{\text{Period}}{\text{Rotation}}$.

Thus, if area $= 2{,}000$ acres, $r = 80$ and Period $= 10$ years, then normal coupe $= \dfrac{2{,}000}{80} \times 10 = 250$ acres.

(3). A comparison of the actual area occupied by the different age gradations with the normal.

(4). If (3) shows that there is an excess of old woods, then, temporarily, more than the normal coupe would be allotted to the period, and *vice versa* until the distribution becomes normal.

V. General Remarks on Formulæ Methods

All these are based on the relations existing between the Growing Stock, Increment and Yield, explained in Sections I

* For a fuller account see Schlich, Vol. III.

and II of Chapter II and the formulæ evolved in Sections III and IV of the same chapter.

It has been pointed out that formulæ methods are subject to certain inaccuracies even when applied to normal forests, and they are subject to additional ones when applied to calculating the yield of real forests, owing to the fact that they are based on quantities and pay little or no attention to the condition of the crop. Obviously, the available yield depends on the condition of the G.S. as well as on its quantity, and no formula based on G.S. or G.S. and Increment can be applied without taking into consideration the actual representation of the age classes.

In spite of the above defects formulæ methods are in considerable use owing to their convenience, and to the impossibility in some cases of applying a more suitable method. Their use is justified provided the yield, as calculated by them, is not followed blindly, but is modified if necessary to meet the actual condition of the forest, and provided that frequent revisions of the working plan are made, at which the yield, previously calculated, is revised in the light of changes in the condition of the forest and the results of periodic remeasurements of the G.S. It is obvious that, as the management improves and the forest therefore approaches a more normal condition, there will be an ever-decreasing difference between the yield as calculated by a formula and the yield based on the existing condition of the crop, as in methods under (*a*) in Section I of this chapter.

VI. The Austrian Method (Schlich, Recknagel's Working Plans)

$$\text{Annual Yield} = \text{Real Increment} + \frac{\text{Real G.S.} \pm \text{Normal G.S.}}{\text{a}}$$

where a = number of years in which it is decided to adjust the excess or deficit; that is, a distinction is made between surplus G.S. and increment; the latter is felled, with the addition of a portion of the G.S. if it is in excess, or after a deduction of a portion, if it is in deficit. The yield, as determined by the formula, is cut in the woods selected for felling during the working plan period in accordance with silvicultural and other requirements.

The merits of the formula depend upon the manner in which

its different elements are ascertained, and these in turn depend upon the nature of the crop and the data available.

Briefly, in modern practice, the normal G.S. is obtained from Yield Tables, the real G.S. by measurement of sample areas, and the increment is considered as the sum of the final mean annual increments of all the woods. In the case of young woods the last is obtained by comparison with yield tables, and in the case of woods approaching maturity, from accurate measurements of the existing volume and the present M.A.I. A modification introduced by Huber substituted the C.A.I. for the M.A.I. It appears (*vide* Recknagel's Forest Working Plans) that the volume formula is now seldom used in Austria to calculate the yield in regular forests; the yield in such cases is regulated by the area of the normal periodic coupe. The areas occupied by each class are determined and, if found to be normal, the normal periodic coupe will be cut over. The yield is calculated for 10 years and comprises the volume and half the increment of the woods which will be felled during that period.

*In Switzerland the Austrian formula is in use for both regular and irregular forests to determine the yield, the normal coupe being only used as a check. Flury's constant is used to determine the volume of the normal G.S. from the C.A.I. (*vide* Chapter II, Section III, p. 24), *i.e.*, Normal G.S. = crI.

The principle of calculating the yield from the real increment modified by the difference between the real and normal G.S. is one common to many methods (compare Brandis' method, p. 63), but is more used in irregular than in regular forests. Usually the C.A.I. is used as being easier to determine than the M.A.I.

VII. Hundeshagen's Formula (Schlich, Recknagel's Working Plans)

Real Yield : Real G.S. : : Normal Yield : Normal G.S.

$$i.e.,\ \mathrm{Yr} = \mathrm{Gr} \times \frac{\mathrm{Yn}}{\mathrm{Gn}}$$

This differs from the Austrian in that there is no distinction in the yield between increment and surplus growing stock. As a

* *Plans d'aménagement des forêts*, Vol. I, International Institution of Agriculture, Rome.

general proposition the statement, that the real yield (~~increment~~) bears the *same* proportion to the real G.S. as the normal yield does to the normal G.S. is, of course, incorrect, since the increment depends on the condition of the G.S., as expressed in the distribution of age classes, and not only on its quantity. Where age classes are fairly normally distributed the formula will give good results, and, where there is a surplus of G.S. due to an excess of old woods it will lead over gradually to more normal conditions ; but, if ~~both increment and~~ G.S. are deficient ~~as a~~ result of an excess of the younger classes, then it will lead to the cutting of more than the true yield. It has the advantage over the Austrian method that the increment need not be determined ; but a yield table must be available from which the values of Gn and Yn (volume of oldest age class) can be obtained. Gr is determined by measurement.

VIII. Von Mantel's Formula

This has already been given in Chapter II, Section IV, p. 25. It is

$$\text{Annual Yield} = \frac{2\ \text{G.S.}}{r}$$

On reference to Chapter II, Section III, it will be seen that this formula is really derived from the formula $\text{G.S.} = I \times \frac{r}{2}$ where I is the volume of the oldest age gradation or the annual yield. Since G.S., where Von Mantel's formula is used, will be obtained from actual measurement and, as has been shown, will usually be a smaller quantity than that obtained from $I \times \frac{r}{2}$, consequently I, the yield obtained from Von Mantel's formula, will usually be less than the true yield.

Von Mantel's formula has the great advantage that nothing is required except the volume of the real growing stock ; the formula or modifications of it are, therefore, widely used. On the other hand, since it is based on the volume of the G.S. only, it has the worst defects of formulæ methods. It will indicate the same annual yield for a forest consisting of immature woods as it will for a forest containing a large proportion of over-mature ones, provided the volume of the G.S. is the same in

both cases. Since the G.S. is usually measured where the method is in use, opportunities will occur for ascertaining the real increment by comparing measurements at different periods. The real increment, thus determined, should be compared with the yield as calculated. The formula is used more for irregular than for regular forests.

It will be observed that, if Von Mantel's formula is accepted as a correct basis on which to calculate the yield, the increment (M.A.I.) per cent. is proportionate to the rotation; thus from the formula $G.S. = I \times \frac{r}{2}$, for an 80-year rotation placing G.S. $= 100$, $I = \frac{100}{40} = 2\frac{1}{2}\%$, similarly for other rotations. This is a useful fact to bear in mind, and when dealing with forests for which accurate information is not yet available, this percentage may usefully be applied as a temporary measure to indicate the maximum annual felling of mature timber permissible.

IX. Modifications of Von Mantel's Formula

Von Mantel's formula, in common with others which require a measurement of the G.S., demands, in order that it may be correct, the measurement of the whole G.S. There is, of course, always a limit below which it is impossible to measure in practice, but, provided measurements are made down to a sufficiently low limit, the accuracy of the formula is not seriously upset. The case is, however, otherwise where there is a high limit to the minimum size measured, as is often the case in less highly developed countries where silvicultural considerations may make it undesirable to fell the smaller classes, or where only timber of comparatively large dimensions finds a market.

Before dealing with these modifications it is important that we should understand exactly what is meant by measurement of the G.S. This operation consists of two processes:

(i) Enumeration of the trees in size or age classes.

(ii) Determining the volume of these classes by multiplying the number of trees in a class by the volume of ~~an~~ (mean ~~individual~~ tree.

For convenience (i) may be called enumeration and (ii) ~~mensuration.~~ Now the minimum size down to which it is

decided to enumerate may or may not be the minimum size down to which it is proposed to measure. For example, suppose it is decided for silvicultural reasons that it is undesirable to fell trees below $3\frac{1}{2}'$ in girth, though the useful bole for purposes of conversion is not restricted by any such limit, then the upper limit for measurement of bole will be different from the b.h. limit for enumeration of trees and the formula required to ascertain the true yield from the G.S. measured will be different from that required in the case where neither trees below $3\frac{1}{2}'$ in girth are enumerated nor the upper part of the tree above $3\frac{1}{2}'$ in girth measured. The latter is the simpler case and we will deal with it first.

(*a*) *Smythies' Formula.**

Where the G.S. is enumerated and measured down to a girth or diameter equivalent to an age of x years *vide* Fig. 11.

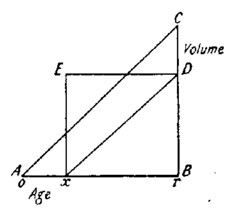


FIG. 11.—SMYTHIES' FORMULA.

The whole G.S. is represented by the triangle ABC. If xD be drawn parallel to AC, and the rectangle ExBD be completed, then the part of the G.S. neither enumerated nor measured = figure AxDC, and the enumerated and measured G.S., say V V, = triangle xBD, and the yield in r–x years = rectangle ExBD = 2ΔxBD = 2V and the annual yield $= \frac{2V}{r - x}$.

The formula presupposes the existence of a normal G.S. below the age of x to supply the yield during the remaining x years of the rotation.

* *Vide Practical Forest Management*, by Trevor and Smythies, p. 101.

(*b*) *Simmons' Formula.**

Where the G.S. is enumerated down to a girth equivalent to $\frac{1}{n}$th of the rotation, but volume measurements include the complete boles of the trees enumerated.

Let G = Volume of G.S.
V = Volume enumerated and measured
a = Volume not enumerated

$$\text{and} \quad n = \frac{\text{Rotation}}{\text{age of oldest } \cancel{\text{class}} \text{ in a age gradation}} = \frac{r}{x}.$$

In this case the annual yield $= \frac{2G}{r}$ because the whole G.S. is utilized as it becomes mature; but only V and not G is known, so the problem is to ascertain the value of G in terms of

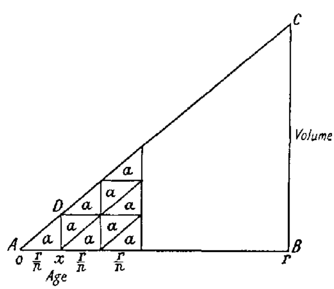


FIG. 12.—SIMMONS' FORMULA.

V, *vide* Fig. 12. Divide the rotation into n parts, erect perpendiculars, and draw parallels as shown; then it is clear that the figure DxBC = V and the triangle AxD = a, and that all the triangles marked "a" are equal (triangles on equal bases and between the same two parallels). Also G = triangle ABC =

* *Vide Indian Forester*, July, 1923. The formula on p. 103 of Trevor and Smythies' *Forest Management* is similar and gives the same result.

$a + 3a + 5a. \ldots (2n \overset{-}{\cancel{+}} 1)a$ (the rotation being divided into n parts).

$$= \frac{n\{a + (2n - 1)a\}}{2}$$
$$= \tfrac{1}{2}n(a + 2an - a)$$
$$= n^2a$$
$$V = G - a = n^2a - a = (n^2 - 1)a$$

$G : V :: n^2a : (n^2-1)a$

Therefore $G : V :: n^2 : n^2 - 1$

Therefore $G = \dfrac{n^2}{n^2 - 1}V.$

and annual yield $= \dfrac{2G}{r} = \dfrac{2n^2}{r(n^2 - 1)}V.$

The formula may also be expressed in terms of r and x. Since $n = \dfrac{r}{x}$, annual yield $= \dfrac{2r}{r^2 - x^2}V.$

Example: Rotation 100 years.

Growing stock down to a diameter equivalent to an age of 20 years enumerated and measured.

$$i.e.,\ n = \frac{100}{20} = 5$$

Volume enumerated and measured = 200,000 cubic feet.

$$\text{Annual yield} = \frac{2 \times 5^2}{100\,(5^2 - 1)} \times 200{,}000$$
$$= \frac{50}{100 \times 24} \times 200{,}000$$
$$= \frac{200{,}000}{48}$$
$$= 4{,}166 \text{ cubic feet.}$$

CHAPTER V

Yield Regulation in Irregular Forests

I. General Remarks

To this type belong all forests in which neither age gradations nor classes are recognizable by area. No exact line of demarcation can be drawn, but, generally speaking, all forests in which the regeneration extends over more than one-third of the rotation will be considered as belonging to this type. The extreme example of the type is found in Selection and Selection Group Forests where regeneration is continuous throughout the rotation.

It will be seen that a forest is irregular from the point of view of management if the area in which regeneration operations may be carried out at one time represents a large proportion of the total. Various silvicultural methods may, however, be adopted for regenerating this area, and in places these may be of such a nature as to produce even-aged woods over small portions of it, so that irregularity does not necessarily mean the same thing from the point of view of management as it does from that of silviculture.

It has already been stated that the regulation of the yield depends on a comparison of the real with the normal forest, and that the quantity and kind of material to be cut will be laid down so that the forest may gradually be brought over into a more normal condition. In regular forests, since age classes are recognizable by area, it is comparatively easy to appreciate the real distribution of age classes and its departure from the normal. In irregular forests, on the other hand, owing to the intermingling of the age classes, such comparison by area is impossible. In a regular forest a mature tree may be said to occupy a definite area, depending on the size of its crown ; in a selection forest, however, a mature tree need not monopolize the area covered by its crown, and it does not therefore seem probable that any method of recognizing the distribution of age

classes in irregular forests from the area occupied by individual trees will ever become possible.

In irregular forests we are therefore deprived of the most useful aid in regulating the yield, and the process becomes proportionately difficult. At the same time an incorrect calculation of the yield may have more serious results in irregular than in regular forests. In the latter—when the yield is by volume—it is customary to cut on a conservative basis, that is to say to cut rather less than the estimated yield; if the undercut is excessive, the fact will be easily recognized and

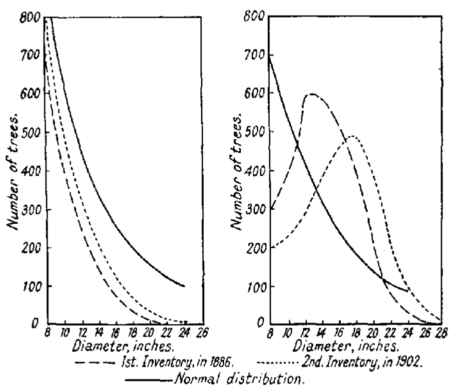


FIG. 13. FIG. 14.

rectified before it has an injurious effect on silviculture. In irregular forests, on the contrary, the effect of serious undercutting is not immediately apparent, and owing to the continuous process of regeneration, it may produce very unfavourable results. Figs. 13 and 14 illustrate the situation in two French selection forests at two periods 16 years apart, taken from Huffel's *Économie Forestière*. These diagrams illustrate both the effect of mistakes and the means which should be taken to rectify them. The normal curve shows that 24″ in diameter is the dimension corresponding to the rotation required, *i.e.*, that trees above this dimension represent surplus G.S. In Fig. 13 the first inventory shows a more or less

proportionate deficiency in each diameter class and a more normal condition is brought about by a reduced yield obtained from light fellings in all age classes. In Fig. 14 the first inventory shows an excess of over-mature trees and, as a result of a too conservative calculation of the yield, this situation is accentuated 16 years later. The correct procedure would now be to fell the over-mature stock as rapidly as possible and make room for the younger age classes by felling more trees in those classes which are shown to be in excess, *i.e.*, from 14" upwards. Temporarily the yield will be increased, but there will be a big drop when the present deficient young age classes reach maturity and the establishment of the normal G.S., which will give the highest *sustained* yield, has been delayed by a mistake in management. Moreover the irregular condition of the forest, which is presumably desired, has been to a great extent destroyed by the accumulation of over-mature stock, a too rapid felling of which may result in the production of undesirable even-aged woods over considerable areas. Whilst it is easy by diagrams such as these to detect a very abnormal distribution of age classes, the data required for drawing the normal curve can only be obtained by long investigation and careful comparison of figures in different areas. When units of the same quality of locality are worked on the same rotation that nearest normal will give the highest *sustained* yield, and, if a unit is progressing towards normality, it should give a higher yield after each inventory ; but one must not, of course, be led astray by temporary increases due to such causes as are illustrated in Fig. 14. Volumes in place of numbers of trees may be used in these diagrams.

The manner in which the Felling Series under the Selection System is divided into compartments or cutting sections has been described on p. 17. It is clear that, unless the yield has been correctly calculated and unless these cutting sections are exactly similar, it will in practice be impossible to cut annually exactly the prescribed yield and at the same time cut each compartment in the prescribed year of the cycle and that year only. The difficulty will, of course, be accentuated by unforeseen occurrences, such as heavy windfalls, in one of the units. In practice, therefore, it is generally necessary to depart from theoretical application of the method. Either each compartment or cutting section is treated as though it were a separate

felling series, its yield being calculated independently and cut in the prescribed year of the cycle : in this case the annual yield from the forest will in all probability vary from year to year. Or the prescribed yield for the series may be cut annually, the arrangement into cutting sections being regarded merely as indicating the sequence of the fellings. The disadvantage of the latter method is that it removes the safeguard against over- or under-cutting provided by the area check which strict adherence to a felling cycle imposes, and, if the yield has been incorrectly estimated, neither the silvicultural character of the forest nor a sustained yield will be maintained.

The yield may be prescribed either by volume or by number of trees. The former method allows a more free hand to the forester. In regular forests the final and intermediate yields are obtained from different areas; in irregular forests they are cut on the same area, generally in one operation. In theory, therefore, the prescribed yield should include both and should indicate the proportion of the same to be obtained from the different diameter classes in order to lead the forest over to a more normal state. In practice it is difficult for the forester marking the trees for felling on silvicultural principles to mark a prescribed yield on a prescribed area ; it is still more difficult for him to allot the yield in a fixed proportion to different diameter classes. In more backward countries, therefore, the prescribed yield sometimes refers to trees above a certain dimension only, the operating forester being given a free hand to cut such trees of other classes as he considers necessary from the point of view of silviculture. The best practice is to keep a strict check on the removal of all classes of material and for the operating forester to cover the area to be felled at least twice, marking in the first instance only those trees the removal of which is essential on silvicultural grounds. It will be understood from the above that the successful management of irregular forests requires a high degree of skill and local knowledge on the part of the forest staff.

II. Regulation by Formulæ

Von Mantel's formula, and the modifications thereof already given, may be used to calculate the yield from final fellings. In irregular forests final fellings and thinnings generally comprise one operation, and the conservative calculation of the

yield in which this formula generally results will therefore be emphasized if trees of all dimensions when felled are counted against the prescribed yield. The Austrian formula given on page 44 may also be used provided it is possible to assess with some degree of accuracy the normal growing stock.

III. The French Method of 1883*

This method was designed to meet the case of forests, mainly in mountainous regions and therefore of a semi-protective nature, in which it had been found by experience that regeneration operations had to be carried out with extreme caution and any concentration of the same usually avoided. The forests, therefore, to which the method is applied are generally worked under the Selection System or under an Irregular Shelter Wood System with a regeneration area ~~block~~, or Quartier Bleu, comprising one-third or more of the total area.† In forests of this nature it is impracticable to separate the final from the intermediate yields and it is necessary to devise a formula which shall include both. Whereas Von Mantel divided the rotation into two parts, the French method divides it into three. Studying the theory of this in Fig. 12 ~~11~~, p. 44 ~~48~~, it will be seen that the proportion of the G.S. in the three parts, oldest, middle and youngest will be 5 : 3 : 1.

Before giving the formulæ actually used the method of making the inventory of the crop will be considered. In other than selection forests two ~~Blocks~~ are formed, the Regeneration ~~Block~~ (*Quartier Bleu*), in which the final fellings are required during the working plan period, and the remainder (*Quartier Blanc*). All trees 20 cms. in diameter and over at breast height are enumerated and measured in both ~~blocks~~ areas. They are divided into two ~~classes~~ : Groups in size

Medium wood 20 cms. and over
Large wood 40 cms. and over

* Based on *Économie Forestière*, by G. Huffel (Vol. III, p. 406 *et seq.*), *Plans d'aménagement des Forêts. Instructions Officielles Institut International d'Agriculture*, and studies of the application of the method in the Vosges.

† The application of this formula to regular forests is not precluded, and it is, in fact, used in the Vosges for forests worked nominally on the uniform system of silviculture, though an investigation on the ground frequently discloses much greater differences in the ages of trees in newly regenerated areas than is covered by the theoretical regeneration period.

Under 20 cms. is classified as small wood and is not measured, thus three diameter classes are formed :

0 to under 20 cms.
20 to under 40 cms.
40 to 60 cms.

That rotation is chosen which produces a 60-cm. diameter tree, and it is assumed that the three diameter classes are equivalent to the three divisions of the rotation. In theory there is no reason why this should be so, but the French have found, by measurements over 40,000 hectares of coniferous forest in the Vosges, that actually, in order to produce a final yield in trees of 60 cms. diameter, it is necessary to maintain on the ground per hectare

200 cubic metres of wood 40–60 cms. and
120 cubic metres of wood 20–40 cms.

This coincides with the proportion 5 : 3, which the division of the rotation into three parts theoretically requires.

If the above proportion is found on the ground, then (subject to any silvicultural peculiarities of the forest) the formula chosen may be applied without further adjustment to calculate the yield.

The formula used is :

$$\text{Annual Yield} = \left\{\frac{V_1}{\frac{r}{3}} + \frac{V_1 \times t_1}{2}\right\} + \left\{\frac{1}{n}(V_2 \times t_2)\right\}^*$$

Where V_1 = Volume of large wood.
,, V_2 = Volume of medium wood.
,, t_1 = Increment per unit p.a. large wood.
,, t_2 = Increment per unit p.a. medium wood.
,, r = Mean age at which it is estimated mature trees will be felled.
,, n = A factor varying according to circumstances.

The first part of the formula provides for the removal of the oldest woods plus the correct proportion of the increment during a period equal to one-third of the rotation, in which

* The original French instructions of 1883 made no provision for the removal of increment of either large or medium wood with the result that surplus growing stock was accumulated at the expense of the younger classes and the forests became more abnormal (*vide* p. 52).

time they will be replaced by the medium woods. The latter portion provides for the removal in thinnings of that portion of the increment of the medium wood which will not be required to replace the old woods.

If the forest is normal or approximately so, that is to say if V_1 and V_2 are found to represent 200 and 120 cubic metres per hectare respectively, and if the increment appears from investigation also to be normal, the formula can be applied as it stands. The French official instructions suggest the following normal figures for the forests to which the formula is usually applied:

$$t_1 = 0{\cdot}01 \qquad t_2 = 0{\cdot}03 \qquad n = 3$$

Where a forest is abnormal the usual practice until recent years of dealing with it was as follows:

A forest of, say, 100 hectares contains 22,000 cubic metres of large wood and 11,000 cubic metres only of medium wood, in place of the normal quantities of 20,000 and 12,000 cubic metres. Thus there is a surplus G.S. of 1,000 cubic metres which may be removed during the period, but there is a deficit of 1,000 cubic metres in the volume of the medium wood, which, before applying the formula, must be made good by transferring to it the smallest diameter classes of the large wood up to 1,000 cubic metres. Thus the yield of large wood is reduced, but the total yield remains higher than it would have been if the forest were normal with no surplus growing stock. In actual operations trees of the diameter of the transferred classes will be treated as immature, thus building up the medium class to normal. If, on the contrary, there were only 16,000 cubic metres of large and 13,000 cubic metres of medium wood, there would be a total deficit of 3,000 cubic metres and of 4,000 cubic metres in the large wood class. The latter would then be brought up to 17,000 cubic metres by a transfer from the medium class of the 1,000 cubic metres surplus in that class. Thus the yield of large wood is increased but the total yield remains less than if the forest were normal. In actual operations trees of the transferred classes will in this case be treated as mature; thus the surplus of medium wood will be reduced, and, since less than the total normal yield is cut, the volume of large wood will be increased.

Essential silvicultural requirements must not, however, be neglected in the fellings, and consequently, the extent to

which these transfers can be made will depend on the nature of the forest in each case. The transfer of a quantity of *large wood* to medium wood and the consequent postponement of its removal may interfere with the growth of the medium and young age classes and accentuate the abnormality of the forest.

The latest official instructions recognize this and state that these transfers should not be considered an essential part of the method. They point out that the co-efficients t_1, t_2 and n_1, which are deduced from the knowledge possessed of the forests (from comparison of volume inventories, etc.) provide the necessary variables in the calculation of the yield which will allow of all the elasticity necessary in its regulation.

When marking for felling, thinnings and improvement fellings are first marked over both Quartiers, and the volume of these (*i.e.*, all trees over 20 cms. diameter), plus that of any windfalls, deducted from the possibility; the balance is then marked in regeneration fellings proper.

This method differs from the formulæ methods already given in that it follows with exactitude no theory of relationship between G.S. and yield. The method is elastic and gives a free hand to the silviculturalist within the limits of the prescribed annual yield. He can make what improvement fellings and thinnings he considers necessary, and, in the case of forests which are irregular but not worked on the selection system, the large regeneration area and the absence of any time limit enable him to vary the speed and intensity of the regeneration fellings according to the requirements of different localities. On the other hand, management retains absolute control of the annual yield, which will be kept steady during a working plan period in spite of any accidents such as windfalls, unless these are on a very large scale. For Selection Forests the method is probably less suitable than those based on the current annual increment.

Example: Communal Forest of Bresse, Vosges. Series 6.
Species: Beech 5·5, Silver Fir 4·5.
Silvicultural System: Selection.
Rotation: 150 years.
Area: 376 hectares.

(*Note:* The forest being a selection one there is no division into *quartiers.*)

VOLUME INVENTORY AND COMPARISON WITH NORMAL.

	Actual *cubic metres.*	Normal *cubic metres.*	+	−
Large wood ...	63,523	75,200		11,677
Medium wood ...	48,217	45,120	3,097	
	111,740	120,320		8,580

The forest is abnormal, having a considerable deficiency of *large wood* and a small excess of *medium wood.* In this instance, however, the method of transfers is not used; instead increment on the *large wood* is placed at the low figure of ·75% p.a., and the *medium wood* being in excess and of vigorous growth, its increment is placed at 2·5% p.a., and " n " is placed equal to " 2 " instead of " 3."

The formula for calculating the yield therefore becomes:

$$\text{Annual Yield} = \overset{\text{Large Wood.}}{\left\{\frac{63{,}523}{50} + \frac{63{,}523 \times \cdot 0075}{2}\right\}} + \overset{\text{Medium Wood.}}{\left\{\tfrac{1}{2}\,(48{,}217 \times \cdot 025)\right\}}$$

$$= 1{,}270\cdot 5 + 238\cdot 2 + 603$$
$$= 1{,}509 + 603 = 2{,}113 \text{ cubic metres.}$$

By the alternative method:

Place $n = 3$ and transfer (if possible) 3,097 cubic metres from medium to large, so that $V_1 = 66{,}620$ and $V_2 = 45{,}120$, then the formula becomes

$$\text{Annual Yield} = \overset{\text{Large Wood.}}{\left\{\frac{66{,}620}{50} + \frac{66{,}620 \times \cdot 0075}{2}\right\}} + \overset{\text{Medium Wood.}}{\left\{\tfrac{1}{3}(45{,}120 \times \cdot 025)\right\}}$$

$$= 1{,}332 + 250 + 376$$
$$= 1{,}582 + 376$$
$$= 1{,}958 \text{ cubic metres.}$$

It is of interest to compare these results with that given by the formula

$$\text{Annual Yield} = \frac{9\,(\text{volume of enumerated G.S.})}{4r} = \frac{9 \times \cancel{105{,}449}\ 111740}{4 \times \cancel{120}\ 150}$$

$$= \cancel{1{,}977}\ 1676 \text{ cubic metres.}$$

This is Simmons' general formula (p. 49) for the special case where G.S. is enumerated for an age of one-third of the rotation and over, *i.e.*, $x = \frac{r}{3}$

Thus the formula for the annual yield $\frac{2r}{r^2 - x^2} V$

$$\text{becomes } \frac{2r}{r - \left(\frac{r}{3}\right)^2} V = \frac{9}{4r} V$$

or direct from Fig. 12

$$G : V :: 9 : 8$$

$$\text{therefore } G = \frac{9}{8} V$$

$$\text{Annual Yield} = \frac{2G}{r} = \frac{9}{4r} V.$$

This formula takes no account of intermediate yields, and consequently the result is comparable only with the yield from large wood in the 1883 formulæ. Also, unlike the 1883 formulæ, it takes account only of the quantity of the G.S. and not of the class proportion.

IV. Yield based on the Measurement of the Current Annual Volume Increment

The best methods of calculating the yield in a Selection Forest are based on the current increment. A word of warning is necessary here. It is not sufficient to determine the current increment and to fix the yield accordingly. It is clear from what has been said in Chapter I, Section III that, if the forest contains an excessive proportion of wood of medium age (at which time the growth is most rapid) yield based on the C.A.I. will be very high ; whereas if mature and over-mature wood

predominates the yield on the C.A.I. basis would be low. If the C.A.I. in either case is cut the policy necessary to secure a more normal forest would be reversed. Only when the forest is normal will the current increment (under any system) indicate the correct yield. Useful as C.A.I. methods are in Selection Forests, the yield determined by them must therefore always be modified according to the observed condition of the forest.

The volume of the G.S. having been measured in any convenient number of diameter or girth classes the results are checked with the previous and subsequent measurements made in the same manner. Thus if:

Vn = Volume n years ago
v = present volume
a = volume removed during these n years

$$\text{then C.A.I.} = \frac{V + a - Vn}{n}.$$

The proportion of the age classes and the general condition of the G.S. will be taken into consideration in determining whether or not the annual yield can be placed as equal to this C.A.I.

Methods of determining the yield based on the C.A.I. require that a complete record shall be kept of all removals and, of course, that these shall be measured and recorded in the same manner and in the same units as the periodical inventories of stock are made. The point is of importance, particularly in new countries where a standard method of measurement has not yet become crystallized and methods of measurement may be adopted by individuals without sufficient regard to future developments.

Until the second measurement has been made, data are lacking for the correct application of the method. As a temporary measure either the past C.A.I. may be estimated by an examination of test trees, or a formula method such as Von Mantel's may be applied. The following example is taken from Schlich, Vol. III, p. 283.*

* This is a simplified form of the Swiss "*Méthode du Contrôle*," which distinguishes between the apparent and the real increment of each class, obtaining the latter by deducting from the former the increment resulting from the trees which have moved up from the class next below. Brandis' and Hufnagl's methods described in the next two sections are also based on the measurements of the current increment.

Example:

INVENTORY PER ACRE IN A SELECTION WOOD.

No. and limit of class. Diameter, inches.	*1st Inventory.*			*2nd Inventory after 10 years.*				
	No. of trees.	*Average Volume per tree cu. ft.*	*Total Volume, cubic feet.*	*No. of trees.*	*Total Volume standing, cubic feet.*	*Vol. of trees cut during 10 years.*	*Total Volume, f + g*	*Increment, h — d*
a	b	c	d	e	f	g	h	i
6 to 12	90	10	900	90	900	200	1,100	200
12 to 18	40	25	1,000	41	1,025	400	1,425	425
18 to 24	15	60	900	21	1,260	120	1,380	480
24 to 30	5	140	700	9	1,260	140	1,400	700
	150	—	3,500	161	4,443	860	5,305	1,805

Remarks: At the start the proportion of the volume in the larger classes is obviously too low, indicating the necessity for a conservative estimate of the yield. 860 cubic feet have been cut during the first 10 years, representing only about 2% per annum on the average volume, whereas the new inventory indicates that the increment has been about 4·1 per cent. per annum, as follows, from Pressler's formula (p. 9).

$$\text{C.A.I. per cent.} = \frac{1{,}800 \times 200}{10\,(3{,}500 + 5{,}300)} = 4{\cdot}1\%.$$

The distribution of the classes is now much better proportioned, but still short in the larger classes, indicating that the policy of building up the growing stock, by cutting less than the increment and conserving trees in the larger classes, must still be followed. It will be noted that the number of trees cut in the last 10 years are I class 1, II class 2, III class 16, IV class 20.

V. Brandis' Method (*vide* Schlich, Vol. III, p. 285)

To appreciate the merits of this method it is necessary to consider the circumstances in which it was originally applied. In 1856 the Pegu teak forests of Burma were brought under proper management and Brandis had the task of regulating their yield. These forests contained only about 10% teak and 90% other species, which were then valueless. Little or nothing was known of the rate of growth of teak, the volume per acre or of its silvicultural requirements. There was a keen demand for teak timber, and it was of urgent necessity to supply this demand and at the same time to ensure that the fellings should not result in a deterioration of the forest property during the time which must elapse before its productive possibilities and silvicultural requirements could be adequately studied. The minimum size of a first-class tree was fixed at six feet in girth, and it was decided to ascertain the number of trees of this class and the number of years which it would take for a second-class tree ($4\frac{1}{2}'$–$6'$ in girth) to become first-class. Thus, if the number of first-class trees (a) were removed in the number of years (n) which it took to replace them, the annual yield would be $\frac{a}{n}$ first-class trees, and the removal of

this number annually would, in theory, result in no diminution of the number of first-class trees in the forest.

Brandis carried out his enumerations by means of strip surveys (100 feet wide), the trees being enumerated in three classes, 3′– 4′ 6″, 4′ 6″–6′, and over 6′. The rate of growth was determined by felling a number of trees and counting the rings, thus ascertaining the average number of years required by a tree to pass from one class into the next. The method in its initial simplicity paid no attention to silviculture and cannot be regarded as anything more than a temporary expedient (albeit an excellent one) for providing against over-cutting. The circumstances under which it was originated would, of course, make it unfair to criticize its author on these grounds. Unfortunately, however, its simplicity, together with the mistaken idea that it could at least do no harm, led to its wholesale adoption in India during the early years of forest management to forests which bore no resemblance to the Burma Teak Forests and which were indeed in many cases quite unsuited to the Selection System.

It is an attractive theory that, if Nature has provided a forest in the past, when uninterfered with by man, she will continue to maintain the same if man steps in and merely removes a surplus of over-mature trees. Unfortunately the theory seldom proves correct in practice. In Burma the subsequent failure of natural regeneration was considered to be intimately associated with the question of fire-protection. In India, in more or less pure forests of light-demanders, or semi-shade bearing species to which the system was often applied, regeneration was dependent on the manner in which the overwood was removed and Nature naturally failed to respond to the haphazard removal of trees of a certain dimension.* The method may, however, be applied to circumstances for which it was designed, provided that its dangers are realized and silvicultural safeguards applied.

The following example, given by Schlich and taken from a Burma working plan, is therefore given of the modern application of the method.

Example: Area of forest, 84,000 acres divided into 50 compartments.

* *Vide* also *Practical Forest Management*, Trevor and Smythies, p. 145.

Two sample plots taken in each compartment and the trees measured therein, giving the following figures for the whole area:

Class I over 7 feet girth	31,523 trees
Class II 6 feet to 7 feet girth	18,114 trees
Class III 4′ 6″ to 6 feet girth	42,768 trees
Class IV 3 feet to 4′ 6″ girth	101,737 trees
Class V 1 foot 6 inches to 3 feet girth ...	150,910 trees

To determine the rate of growth, countings on 198 trees were made, which gave the following averages:

Girth.	*Age in years.*	*Years required to pass through class.*
1′ 6″	31	
		29
3′ 0″	60	
		33
4′ 6″	93	
		37
6′ 0″	130	
		26
7′ 0″	156	
	Total ...	125

Hence the rotation was fixed at 160 years and divided into five periods of 32 years each. From observations made in this and other forests in Burma it was ascertained that the following percentages of sound trees are likely to survive and be available for utilization:

Class I,	95% giving thus	29,947 trees	
Class II,	85% ,, ,,	15,397 ,,	133,932 trees.
Class III,	70% ,, ,,	29,938 ,,	
Class IV,	50% ,, ,,	50,869 ,,	
Class V,	25% ,, ,,	37,728 ,,	
		163,879 trees.	

As it requires 125 years to pass a tree 1′ 6″ in girth into the first class the average number of trees passing annually into the first

class would be $\frac{133,932}{125} = 1,071$. Also there is a surplus of trees over 7′ in girth, as it is not necessary to keep more than half the average yield during a period of such trees (*i.e.*, $1,071 \times 16 = 17,137$ trees) standing in the forest. The balance $29,947 - 17,136 = 12,811$ might be removed in addition to the actual increment, that is 400 trees p.a. over the 32-year period, and the theoretically correct yield would amount to:

Yield representing the annual increment	=	1,071 trees
Removal of surplus stock	=	400 trees
Total permissible yield, annually ...	=	1,471 trees

To preserve mature trees for regeneration and on account of the increased value of trees of 8 and 9 feet in girth the yield is reduced to 1,000 first-class trees annually.

Note: The assumption that the first class is recruited by 1,071 trees annually in the first 32 *years* is theoretically incorrect, as may easily be seen if the age classes are represented on a diagram as in Fig. 15 (p. 70).

In 32 years all the 15,397 second-class trees will become first-class, since the smallest of these only takes 26 years to pass through the second class. In addition, one thirty-seventh of the third-class trees annually become second-class, and after 26 years the first lot of these will become first-class; during the remaining 6 years of the period $(32 - 26)$ 6/37ths of the original third-class trees, *i.e.*, 6/37ths of $29,938 = 4,855$, will pass into the first class. Therefore the total yield during 32 years is $15,397 + 4,855 = 633$ trees per annum and not 1,071.

It is obvious that there is a big deficit of II-class trees.

*VI. The Volume Unit Method**

Brandis' method has the serious defect that it takes no account of the fact that in the majority of irregular forests silvicultural requirements do not permit of the restriction of fellings to trees of a certain size. If, however, the yield is to be regulated by numbers, it will be obvious to all with any

* "Volume Unit Method" is not a standard and accepted term; it is used for convenience here to cover two methods which resemble one another and to contrast them with Brandis' Tree Unit Method.

experience of practical forestry that it would be futile to prescribe in advance the numbers of trees to be felled in each size class in such forests as these. To improve upon the system and obtain a method of calculating the yield which shall make it possible to cut the increment from any class according to silvicultural requirements, it is necessary to substitute for numbers a unit, in which it shall be possible to represent the proportionate volume in each class. Enumerations having been carried out as in Brandis' Method the volume of an average tree in each class is determined by measurement or estimate and volume tables are thus prepared. A high degree of accuracy is not essential, for, in marking the trees for felling, the same volume tables will be used and a tree will have a volume arbitrarily allotted to it in accordance with its girth or diameter, thus ensuring agreement of the yield realized with the yield prescribed. The comparative volume of the trees in the different classes may be expressed in the form of multiples of a common unit or in cubic feet. There are objections to expressing in a standard form of measurement a yield which—if volumes have been estimated—may be far from accurate, and the unit method has the additional advantage of reducing the calculations.

*(a) *Application to a Selection Forest.*

In 1893 an Austrian forester, Hufnagl, devised a method on the above lines for use in remote Selection Forests. The formula he used for calculating the annual yield was as follows :

$$\text{Annual yield} = \frac{n_4}{a_4 - a_3}V_4 + \frac{n_3 - n_4}{a_4 - a_3}V_3 + \frac{n_2 - n_3}{a_3 - a_2}V_2 + \frac{n_1 - n_2}{a_2 - a_1}V_1$$

where a_1, a_2, a_3 and a_4, and n_1, n_2, n_3 and n_4, and v_1, v_2, v_3 and v_4 represent respectively, the *mean* age, number of trees and average volume per tree respectively in each class from the lowest up. Hufnagl considers that the period of exploitation should equal approximately $a_4 - a_3$ years ; the formula will be incorrect if it exceeds the time taken by any class to

Forest Working Plans, Recknagel, 2nd edition, p. 101.

pass into the next (*vide* footnote, p. 71). Hufnagl also contemplates checking the result obtained with that obtained by the C.A.I. method (*vide* Section IV of this chapter).

To analyse the effect of this formula:

(1) $a_4 - a_3$, $a_3 - a_2$, etc., will give the length of time required to pass from the middle of one class to the middle of the next highest, in contrast to Brandis' method which determines the length of time required to pass through each class. The two methods, when used to calculate the number of trees which reach the higher class during a certain period, will give slightly different results: but the difference is not important, and Brandis' age limits could be substituted for these average ages if desired.

(2) The first expression in the formula will clearly result in the removal of the first-class trees in the period in which they will all be replaced by second-class trees.

(3) The second expression will result in the removal of those second-class trees, which are not required to replace the first-class trees, in the period required for the second-class trees to become first-class. Similarly for the subsequent expressions.

(4) It is, therefore, clear that the application of the formula without modification will result, in theory, in the maintenance of the classes in the exact proportion in which they are at present.

(5) The formula assumes that the trees in each class, not required to recruit the higher class, will be available in the yield, *i.e.*, that none will die and rot between two felling operations. Intensive management and a short felling cycle might justify this assumption.

Hufnagl's method is certainly preferable to Brandis' for most types of Selection Forest. It is clear, from consideration (4) above, that it would not be correct to apply it as it stands to any forest which was not approximately normal, also, from consideration (5), that in many cases it would be necessary to make allowance for unmerchantable trees as in Brandis' method.

The yield may also usefully be checked with the yield obtained from Simmons' formula (p. 49).

The lowest class enumerated will normally be that which gives the smallest timber ordinarily merchantable in the principal fellings. Any trees below this size, which have to

be felled for silvicultural reasons, may or may not be saleable, and will not be counted against the yield. It may, however, be considered desirable to enumerate a class, below that ordinarily merchantable, in order to obtain additional information regarding the distribution of the growing stock within the rotation.

(*b*) *Application to Conversion from Irregular to Regular Forest.*

The forest having been divided into periodic blocks the problem is to ascertain the yield (annual) in the current regeneration block. The existing irregularity of the forest will, of course, make it impossible to apply the yield tables for regular woods, even if such are available. The problem, therefore, is one which is similar to that dealt with in Selection Forests. There is this difference: that during the period the whole of the existing growing stock must be removed in addition to half the increment which would be laid on during the period, if absolute regularity is aimed at. Such regularity will seldom be obtainable, but in any case the yield will be based on the merchantable growing stock available, and not only on the increment and surplus growing stock. Such conversions will in most cases be required in remote places, where wood of small dimensions cannot easily be disposed of, and we may, therefore, assume that there will be a minimum girth or diameter limit for the principal fellings as in the selection system.

The method of determining the yield will be best understood by means of an example, and the following is based on an Indian Working Plan (Rawalpindi) for the conversion of a Pine Forest, hitherto worked (nominally) on the Selection group system, to the Regular system.

Example: The woods allotted to P.B.I., the current regeneration block, are to be regenerated in 25 years; they contain trees of all dimensions. Trees below $3\frac{1}{2}$ feet in girth are not normally merchantable and, where occurring in groups of sufficient size, will be left to form part of the next crop. In any case, where felled for silvicultural reasons, they will not be counted against the yield.

The table on p. 70 gives the inventory of P.B.I., the figures in the final column being determined from a graph prepared from the results of a large number of ring countings.

The total volume available for removal during the 25-year period is 319,470 plus half the increment laid on in each class during this period. There is no increment to be calculated for Class I, since the yield of any tree above 7′ 6″ in girth is arbitrarily placed at 5 units and considered as such when the trees are marked.

Girth Class.	*Number of Trees.*	*Average Volume per tree in cu. ft.*	*Volume Unit.*	*Total Volume Units.*	*Average age of tree at lowest limit of Class.*
I over 7′ 6″	8,500	250	5·0	42,500	140
II 6′ 6″ to 7′ 6″	16,300	165	3·3	53,790	120
III 5′ 6″ to 6′ 6″	33,500	122	2·44	81,740	100
IV 4′ 6″ to 5′ 6″	49,200	85	1·7	83,640	80
V 3′ 6″ to 4′ 6″	57,800	50	1·0	57,800	62
				319,470	

As regards the other classes, the increment can be determined on the assumption that each class contains the number of age gradations represented by the number of years which a tree in the

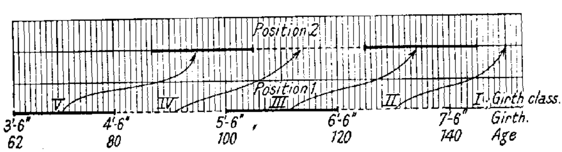


Fig. 15.—Progress of Girth Classes in 25 Years.

class takes to pass through the class. Thus in the fifth class there are 18 age gradations and in the other classes there are 20. During the period 25 years will be added to each of these gradations, so that the fifth class will move from 62–80 to 87–105 years, and 5 of the original 18 gradations will now be in the III class, and the remaining 13 in the IV class (*vide* Fig. 15), and the increment of 5/18 of the class will be 2·44 − 1·0 = 1·44, and of 13/18 1·7 − 1·0 = 0·7 units per tree. Similarly for the other classes, the whole of the II class becoming I.

The increment during 25 years will therefore be as follows:

$$\text{Class V}\left(\frac{5}{18}\text{ of }57{,}800\times1{\cdot}44\right)+\left(\frac{13}{18}\text{ of }57{,}800\times0{\cdot}7\right)=52{,}340$$

$$\text{Class IV}\left(\frac{5}{20}\text{ of }49{,}200\times1{\cdot}6\right)+\left(\frac{15}{20}\text{ of }49{,}200\times0{\cdot}74\right)=46{,}990$$

$$\text{Class III}\left(\frac{5}{20}\text{ of }33{,}500\times2{\cdot}56\right)+\left(\frac{15}{20}\text{ of }33{,}500\times0{\cdot}86\right)=43{,}050$$

$$\text{Class II}\quad 16{,}300\times1{\cdot}7=27{,}710$$

Total Increment 170,090

$$\text{*Theoretical available increment for felling}=\frac{170{,}090}{2}=85{,}045\text{ units.}$$

It is certain that in practice the above theoretical increment will not be produced, many trees not putting on the normal increment owing to damage by fire and other causes. Comparing the enumerations for the previous working plan with those for the present one, it appears that during the past 15 years about 60% of the theoretical increment, calculated as above, has been obtained in similar forests.

The increment, therefore, to be allotted to the yield annually will be

$$60\%\text{ of }\frac{85{,}045}{25}=2{,}041\text{ units}$$

$$\text{and total annual yield }\frac{319{,}470}{25}+2{,}041=14{,}820\text{ units.}$$

* A calculation, on these lines, of the increment for half the period cannot be substituted for the above, owing to the fact that, for the purposes of calculation, the increment does not progress regularly and ceases altogether at 7′ 6″. Thus the increment for $12\frac{1}{2}$ years in the II class would appear to be $\frac{12\frac{1}{2}}{20}\times16{,}300\times1{\cdot}7$, since one of the 20 age gradations moves up each year; whereas, to agree with the above, it should be $\frac{12\frac{1}{2}}{25}\times16{,}300\times1{\cdot}7$. The other classes are also affected, but in the opposite direction, as will be apparent if the calculation is studied in relation to Fig. 15. The fact must be borne in mind that, in order that increment for half the period may be the same as half the increment for the period, the period of exploitation must not exceed the time required to pass from any class into the next. (Compare Hufnagl's method.)

This yield is further reduced by 10% to provide a reserve of seed-bearers at the end of the period in case of further destruction by fire, so that the prescribed annual yield = 13,330 units.

The above calculation of the increment does not take into consideration the increment during the period of trees below 3′ 6″ in girth as represented by their progressive advance into the larger classes. As has been stated the majority of these trees are to be retained to form part of the next crop; but a number, particularly where occurring as single trees or in small groups, will have to be felled for silvicultural reasons. In order, therefore, to ensure that trees which have not been enumerated shall not be counted against the prescribed yield when marking fellings, a table is drawn up from the age-girth graph showing the minimum girth, which will entitle a tree to be counted against the yield in each year of the currency of the plan thus:

1st year	... ...	3 feet	7 inches
2nd ,,	... ...	3 ,,	8 ,,
3rd ,,	... ...	3 ,,	8 ,,
4th ,,	... ...	3 ,,	9 ,,
5th ,,	... ...	3 ,,	10 ,,

e.g., in the 5th year a tree below 3′ 10″ in girth had a girth of less than 3′ 7″ when the enumerations were made, and was therefore not enumerated.

It is clear that the above method can also be applied to calculating the yield in a Selection Forest, in which case only the increment and surplus growing stock will be taken into consideration. Used thus, it will be more elaborate than Hufnagl's method, since it considers the increment of each girth class separately, and in fact it will, in principle, resemble the French Méthode du Contrôle.

PART II

PREPARATION AND CONTROL OF A WORKING PLAN

CHAPTER I

PRELIMINARY MATTERS

No successful productive enterprise can be conducted without foresight and a considered plan of action. In the case of forestry, where the one who sows is only exceptionally the one who reaps, and where harvesting is not a single operation but one extending—through thinnings—throughout a large portion of the life of the crop, on the manner of carrying out of which future production and rate of growth largely depend, the necessity is obvious for a written plan of management, which will ensure that continuity of action which the maintenance of a productive forest requires.

In the case of a very small estate the plan may be a brief and simple one, dealing only with the silvicultural problems involved and the regulation of the yield. But plans of management in many, and indeed in the vast majority of cases, have to be made for forests extending over large tracts of country, where perhaps many types of forest are represented and consequently various problems require solution. It is clear that in such large areas proper treatment of individual crops, leading to the maximum productivity of the whole, can only be ensured by providing a considered scheme, covering a number of years, in which all the problems with which the management will be faced are dealt with in detail. Moreover in such circumstances it is probable that, in addition to problems relating to silviculture and the regulation of the yield, others relating to such

matters as providing for right holders, fire protection, construction and maintenance of roads, and other works for the extraction of produce, etc., will have to be dealt with. All such matters will require consideration beforehand and planning for a series of years.

A working plan may be prepared for a single forest, a division or unit of supervision, or even a number of such divisions : one plan, however, should never cover forests under different ownerships.

In settled countries when a working plan is required for a forest, whether privately or publicly owned, it is generally possible to proceed immediately with considering the details of the plan : for the location and extent of the forest will be shown on maps, its boundaries demarcated, and there is likely to be available a considerable mass of information regarding the general character of the forest growth and any special considerations affecting its management. Foresters in various parts of the British Empire are, however, still liable to be confronted with the situation that none of the necessary preliminaries to the preparation of working plans have yet been carried out and it is therefore desirable to consider briefly here what is required before a commencement can be made with forest working plans and the procedure which would normally be followed in the case of forests owned by the State.

The ideal sequence of events would be somewhat as follows :

(I). The framing of a State Forest Policy.
(II). The enactment of Forest Laws.
(III). The location of State Forests.
(IV). The classification of forests as :

(*a*) Maintained for commercial purposes.
(*b*) ,, ,, physical reasons.
(*c*) ,, ,, satisfying the agricultural and domestic requirements of the local population.

(V). The demarcation of the forests.
(VI). The record and settlement of rights.
(VII). A topographical survey and the preparation of maps.

And the following, which should be carried out preferably by the officer in charge of the preparation of the working plan:

(VIII). Ecological survey, *i.e.*, study of Sites, Forest Types and History.

(IX). Division of the area into compartments (possibly postponed until later).

(X). Submission of the Preliminary Report on which the working plan will be based.

I. The Framing of a State Forest Policy

It is not the place here to enter upon the considerations which should guide the drawing up of a forest policy to be followed by the State. It is sufficient to say that only by laying down a policy which is both desirable and practicable, and maintaining it regardless of political considerations, can forest conservation be made effective. In no country in the world are forest problems more complex and is the pursuit of a forest policy more necessary than in the Indian Empire, and, as a useful example to foresters and others, an extract from the Government of India resolution dealing with forest policy is therefore printed in Appendix III.

II. The Enactment of Forest Laws

A forest policy must be supported by a Forest Law. To obtain an appreciation of the necessity for special laws relating to forests and their nature a study of Forest Law, by B. H. Baden-Powell, is recommended.

III and IV. The Location and Classification of State Forests

In accordance with the policy adopted and as provided for in the laws which have been enacted, the forest areas which it is desired to bring under control of the State may now be indicated. If a classification under the headings given is possible useful information regarding forest resources will be obtained and the working plan requirements will be more easily foreseen.

V. The Demarcation of the Forests

The question whether the accepted policy requires the inclusion or exclusion of certain areas will have to be carefully considered. Intricate boundaries resulting from a desire to include

or exclude small areas should in so far as possible be avoided. A long and (if artificial) straight boundary is always desirable from the points of view both of cheap maintenance and avoidance of disputes. Natural boundaries, *if clearly defined and accurately shown on a map*, are useful as they cannot be altered and save expense. Rivers and streams make the best natural boundaries; ridges, spurs and ravines may require some artificial definition. In tracing boundaries on spurs and ravines work should proceed uphill along the former and downhill along the latter, *i.e.*, in the opposite direction to which they usually branch. Artificial boundaries may be marked by cut lines, ditches, walls, hedges, masonry pillars, solid stone pillars or loose stone pillars according to circumstances. Numbered masonry pillars provide the best means of demarcation, as they give an accurate position which is not easily altered. Permanent roads also make good artificial boundaries. The best form of boundary record is an *accurate* map on an *adequate* scale. Where boundary disputes are liable to occur it is, however, desirable to supplement the map with a boundary register in which the nature of the boundaries will be described and the ownership of adjoining property given; where numbered pillars are used the position of each and the distances and bearing between adjoining pillars will be given.

VI. The Record and Settlement of Rights

The customs and necessities of the surrounding population generally compel the recognition of "rights" over at least part of the forest area in most forest tracts. These may be rights of way or rights to certain forest produce. The method of dealing with these rights will depend upon the forest policy and forest law of the country in question; forest management cannot be successfully carried on unless these rights are accurately known and regulated. Where the rights claimed are considerable the forest law will generally have to be invoked for their final settlement and record in the interests of all parties.

VII. Topographical Survey and the Preparation of Maps

If the forests have been demarcated before the general survey of the country has been carried out due attention can be

given to the special considerations affecting the mapping of the forests when the general survey is undertaken. When a country is surveyed, only the position of the more important natural features is accurately determined and mapped (this applies particularly to mountainous and forest-clad areas), and these do not necessarily include all those natural features which might be selected as convenient forest boundaries. Thus, if survey precedes demarcation and the forest boundaries are subsequently entered on the survey maps, the latter may show no evidence of a natural feature such as a spur or ravine the existence of which on the ground was the determining factor in selecting the position of the boundary in question ; or the map may be actually misleading in that the physical feature in question, though shown, is given a slightly incorrect geographical position due to the fact that it has been sketched in and not surveyed.* As the cost of a survey depends on the amount of detail accurately shown on the map, the essential requirements in this respect from the forest point of view must be carefully considered beforehand. The requirements will not be the same in the case of large unbroken tracts of forests in the plains as they will be in the case of small detached forests in mountainous districts, nor in the case of forests used mainly for grazing as those producing valuable timber. Very dense forest growth will greatly increase the cost of an accurate survey of natural features, often to a prohibitive extent. The scale of the map need not be larger than is necessary to show accurately the detail required. It may be assumed that measurements can be made to an accuracy of about 1/100th part of an inch, so that on a map on the scale of 6″-mile measurements can be made within about 3 yards of reality. Scales used by the Ordnance Survey of Great Britain are 1″, 6″ and 25·344″ to the mile ; the last is sufficiently large to show accurately the position of a boundary pillar. In India 1″, 2″ and 4″ scales are used.

VIII. Ecological Survey, i.e., Study of Sites, Forest Types and History

Before proceeding to the preparation of the first working plan for an area, it is essential to make a preliminary reconnaissance to determine the nature of the forest on which the

* An aerial survey may with advantage be carried out before demarcation.

management proposals will be based. It is unlikely that the investigations described below will be completed at this stage, they will probably form an important part of the field work referred to in Chapter II.

Plant ecology in its relation to Forestry is one of the most important subjects for study under the Foundations of Silviculture and can only be dealt with in the briefest manner here.*

Students of forestry have long recognized that the influence of climate and the chemical and physical nature of the soil produce sites of varying ecological character with corresponding variations in the silvicultural conditions and the required silvicultural treatment. Only in recent times, however, has it been realized that a knowledge of ecology and of the factors governing plant succession may be an essential part of the equipment of a practical forester. Forestry was developed in the countries of Western Europe mainly by empirical methods before the science of ecology received any widespread attention; its successful development in this manner was assisted by the fact that the forests in these countries generally represented, if not climax types, at least sub-climax types, *i.e.*, types to which the combined effects of biotic, edaphic and climatic conditions had given a considerable measure of stability. When forest conservation and management were initiated, in comparatively recent times, in other continents, the original foresters, whose many preoccupations left them little leisure for

* The following literature on the subject is suggested for study. *Plant Succession*, by Prof. F. E. Clements, published by the Carnegie Institute of Washington, U.S.A., gives a general survey of the subject. *Foundations of Silviculture*, Vol. I, by Prof. J. W. Tourmey, published by Chapman and Hall, London, deals with it more particularly from the point of view of the forester. *Some Ecological Conceptions*, by R. Bourne, *Empire Forestry Journal*, July, 1934, provides a valuable summary and discussion of the different views at present held by ecologists regarding plant succession and climax types. *Regional Survey*, by R. Bourne, Oxford Forestry Memoir No. 13, Clarendon Press. *The Theory of Forest Types*, by A. K. Cajander (English Edition, 1926), deals with a system of classification of sites independent of the tree growth and based entirely on plant indicators in the ground vegetation. As regards this last work, the student must be warned against accepting the conclusions, which appear to have been proved correct for certain countries, as of universal application. Forests in some countries do not permit of classification by the soil flora alone, and in certain cases, ground flora plant indicators may be definitely misleading if used to determine the value of the site for the purposes of trees, since the latter may be affected by a deeper layer of the soil than the former.

experiment and scientific research, were naturally inclined to adopt methods of silvicultural treatment learnt in Europe, which had proved to be efficacious in their country of origin. Nor should it be supposed that an intelligent application of these methods necessarily involved failure. Under certain circumstances diagnosis is easy, and in others, where natural conditions are favourable, a treatment, even if it is not based on a careful and accurate diagnosis, may be successful. Sooner or later, however, the practical forester who extends his experience will come across cases in which none of the various treatments which he has been taught to apply produces the desired results. Such cases will occur when the valued tree species is not a natural dominant on the site on which it appears, and owes its present prevalence to conditions temporarily favouring it in one stage of progress towards, or regression from, the climax type, which would in the ordinary course of Nature eventually result from the combined climatic and edaphic characteristics of the site. An early solution of the problem is then most likely to be found by investigations covering both cause and effect. The former is, firstly, the climate and soil, and secondly biotic factors both present and past. The latter is the type of vegetation, which will probably yield evidence of the causes which have produced it, and thus supplement the knowledge derived from a study of the climate and soil and enable gaps in the known history of the crop to be filled in.

In order that the silvicultural prescriptions of a working plan may be based on accurate appreciation of the silvicultural possibilities of the different sites, it is, therefore, desirable that investigations on the above lines should be carried out for the whole area, and the sites and forest types, which occur on them, classified.

The forester who is tackling the problem of the classification of sites and forest types for the first time will naturally desire to study what others have done in the same field. Few examples are at present available, but an excellent one of what may be required is provided by *Indian Forest Records*, Vol. XIX, Part III, dealing with the classification of Sal Types (Shorea Robusta, one of the principal Indian timber trees) by H. G. Champion and others. A typical instance of the failure of a silvicultural treatment, resulting from non-recognition

of the biological nature of a site and disregard of the history of the origin of the existing forest type, is provided by *Type* $D_2(b)$ *Wet Sal* (p. 64), in the above work and the conclusions are briefly summarized below :—

As a result of biotic interference (firing) a forest of Sal and other fire-resistant deciduous species appears on a site on which a less valuable evergreen forest is the climatic climax. Foresters introduce fire-protection and endeavour to regenerate the Sal forest under the Selection System—a natural system of silviculture, which will necessarily fail where natural conditions are unfavourable to the desired species. Increasing invasion of evergreens and complete absence of Sal regeneration suggests the re-introduction of firing, but the evergreen forest is found now to have reached a stage where it is no longer vulnerable. A recognition that evergreen forest is the climax type, and that open Sal forest is a sub-climax type, resulting from firing, leads to the conclusion that a valuable Sal forest cannot be maintained on the site by natural methods, and clear fellings followed by cultivation of field crops, sowings of Sal and controlled firing is suggested.

Foresters in Great Britain will derive assistance from a pamphlet entitled *The Natural Woodlands of Britain and Ireland*, by Dr. M. L. Anderson (Holywell Press, Oxford), which, besides a classification of woodlands, includes a classification of waste lands for afforestation purposes ; further investigations will probably result in amendments to these classifications.

As a preliminary then to prescribing the treatment of any forest of considerable extent it will be seen that the forester should endeavour :

(*a*). To distinguish the different types of forest which occur.

(*b*). To determine the climatic and edaphic characteristics of sites which have given rise to these types.

(*c*). To determine to what extent biotic influences have modified the type which the climatic and edaphic conditions would normally produce. For this purpose the history of the forest must be studied from records and observations.

(*d*). To decide which of the types represented are climax types, and which are sub-climax types, and what are the conditions governing the latter.

(*e*). To distinguish types which represent stages in succession and regression respectively.

To say that no working plan should be prepared until a satisfactory classification of sites and types has been effected would be to advance a counsel of perfection. A considerable period of study may be required to form correct conclusions and the area covered by one working plan will seldom provide material for the complete study of the important types which it contains. A working plan, for a limited period, based on incomplete knowledge is in the meantime likely to be less harmful than uncontrolled felling. But, until the treatment of any forest type is based on a correct appreciation of the biological character of the site and of the various influences which have produced the existing type, there is no certainty that it will produce the desired effect.

Where a complete Regional Survey for the purposes of Agriculture and Forestry has been carried out on the lines contemplated by Bourne in his Memoir on the subject (footnote, p. 78), the greater part of the information required to be collected under this section will already be available.

IX. Division of the Area

It may or may not be desirable to proceed with the division of the area into compartments at this stage. From what has been said about the constitution of compartments in Part I (p. 18) it is clear that it is desirable to decide on the type of silvicultural system before the division is made. Compartment boundaries should be of such a nature that they are easily located and the instructions on forest boundaries in Section V above apply generally to compartment boundaries also, except that the special precautions required in the case of the former to prevent boundary disputes are unnecessary in the case of the latter. Solid stone pillars on which the compartment numbers are engraved on the side facing away from the compartment to which they relate are convenient, but are generally considered unnecessarily expensive. In laying out compartment boundaries, the accessibility of the compartment is one of the most

important points to consider, and an endeavour should be made so to arrange matters that every compartment is—or will later be—served by a road or ride. On sloping ground the lower boundary of the compartment should, if possible, be such a road or ride.

X. *The Preliminary Report*

Having studied the forest as indicated in Section VIII above and investigated, in so far as they are available, figures for rate of growth, etc., which will influence the rotation to be adopted and the method of regulating the yield, the forester responsible for the preparation of the plan will submit a preliminary report to the owner. This report will deal with the history and past management of the forest and the objects of, and proposals for, future management, such as silvicultural systems to be adopted, method of calculating the yield, etc. The preliminary report, accepted or revised by the owner, will then represent the instructions in accordance with which the working plan must be prepared, and which must not be departed from in principle without the owner's approval.

CHAPTER II

Field Work

I. Ecology and Rate of Growth

The work described in Section III of the last chapter will be continued and completed and figures for the rate of growth of the principal species collected and examined for the purpose of determining the rotations to be adopted. Until the compartments, the smallest permanent units with which we are concerned in management, have been examined in detail, ideas regarding the methods of management and rotations to be adopted cannot be crystallized into prescriptions ; but it is desirable, and generally essential, that ideas on these subjects should have been formulated before that step is undertaken.

II. Description of Compartments

In accordance with the basic principle that the treatment of the whole will depend on the treatment which is practicable for its parts, every compartment will now be subjected to an investigation similar to that carried out for the whole area and its position in the classification of sites and types—where such classification has been prepared—recorded. In addition, the technical nature of the crops must be investigated and the treatment required for each compartment individually considered.

If the crop is an irregular or mixed one and the area of the compartments large, it will sometimes be of great assistance in visualizing the crop to make a stock map of the area, sketching in the different species or age classes by means of colours or conventional signs.

If the existing constitution of any compartment renders it unsuitable to serve as a working plan unit, it will have to be decided whether this unsuitability is permanent or transient. In the former case its boundaries will have to be altered, in the

latter a separate sub-compartment must be formed and separately described. An alteration of compartment boundaries cannot generally be lightly undertaken, for an alteration in the identity of long-established units, recognized in records and by the executive staff, may cause much inconvenience.

In the Description of Compartments, accompanying the Working Plan report (*vide* Chapter III), the amount of information and the manner in which it is presented will vary according to circumstances, but it is generally tabulated somewhat as follows:

(1). Number of compartment.
(2). Total area.
(3). Boundaries.
(4). Locality.
(5). Species.
(6). Description and history of growing stock.
(7). Quality.
(8). Reduced area.
(9). Density.
(10). Rights.
(11). Treatment.

Area. Areas, if not already known, will be ascertained from a map by use of a planimeter. If, within the boundaries of a compartment, there are any areas unsuited for, or not intended for, the production of forest, their area must be stated and the net area of forest land given.

Boundaries. Should be briefly stated so as to indicate the position of the compartment.

Thus :—*North*—Main road Monmouth to Gloucester.
East—Compartment 84.
South—Wye river.
West—Compartment 82.

Locality. Give information regarding situation and soil in so far as they affect the crop and its treatment. If sites have been classified, identify the locality in accordance with this classification.

Sample description :—" Elevation 200–400 feet. Lower slope of valley. N.W. aspect. Sheltered. Slope steep. Loam. Fertility and depth good."

Species. If more than one species is present, the proportion of the different species may be represented thus :—Oak 0·7, Beech 0·2, Ash 0·1.

Growing Stock. The technical nature of the main crop species, and subsidiary species and the undergrowth will be described and the origin and history given. If any inventory has been made the results should be recorded. It is important to recognize and note the significance of the undergrowth, both as regards its effect on regeneration and growth of the trees, and as indicating fertility or the reverse.

Whilst all information of importance must be given, care should be taken to avoid making the description verbose, and to avoid constant repetition. Where forest types have been classified, the vegetation can be referred to its type, and no useful purpose will be served by repetitions of the type characteristics against compartment after compartment.

Sample description for a plantation :—" 15–20 years old Scots Pine with considerable blanks, occupied by bracken. Average height 22'. Planting was carried out between 1910 and 1915, but owing to the War failures were not made good."

Sample description for a natural forest :—" Pine poles 30-35 years old, with a few trees of the previous crop scattered amongst them, occupy most of the area ; but, over some 30 acres south of Panjar Village, there is a very open crop of mature trees with no regeneration or undergrowth. The position is the result of firing, and the open crop the effect of repeated firing followed by excessive grazing, resulting in a bare hardened soil into which the seeds cannot penetrate. The forest was fired in 1912, 1910, 1903, 1899, 1896, 1894 and 1890."

Quality. The mensuration quality class of the locality for the species in question should be given (*vide* p. 20). It is desirable that a compartment should only contain one quality class. This, however, will often be impossible to arrange, particularly in hill forests. If there is considerable variation, it may be necessary to establish an intermediate quality class by assessing the proportion assignable to each quality ; thus quality I, 0·6 ; quality II, 0·4. The reducing factor for the productivity of the forest will then be calculated from this proportion.

Reduced Area. In accordance with the quality class, will be calculated as explained in Part I (p. 20).

Density (*vide* p. 29). The yield will depend not only on the productivity of the locality, as evidenced by the reduced area, but also on the density of the crop. Comparative densities must be assessed by a fixed standard, the most convenient of which is a fully stocked forest. To obtain the maximum productivity it is probably necessary to have a wood fully stocked throughout its life, but a young wood which is only stocked to a density, say, of 0·6 may, by the time it is mature, produce final fellings of a volume equal to that of an existing mature wood of a density of, say, 0·8. We must, therefore, consider the objects which our density figures are intended to serve. If they are intended to be used for calculating the volume of intermediate yields, then the existing density of immature crops is of importance. If only final yields are under consideration, then it may be sufficient to assess only the density of those compartments which will come under the axe during the working plan period. If it is desired to utilize the density figures to assist in equalizing final yields over periods of the rotation, then an endeavour should be made to assess the density which may be expected from each compartment at maturity. In the last case only considerable gaps in the canopy of young crops will be considered. In poorly stocked forests the estimates of different individuals are likely to show considerable variation and a high degree of accuracy cannot be expected. Where enumerations are carried out these may provide a more reliable guide.

Rights. If any rights exist they must be stated and, if special measures are necessary to satisfy them, these must be given under " Treatment."

Treatment. Under this heading will be given all operations which require to be carried out at an early date, whether in connection with final, or intermediate fellings, or cultural operations, etc. The optimum treatment should be indicated, at any rate in the first instance : though subsequent consideration of the area as a whole may prevent the optimum treatment being applied to each unit.

Referring back to the description of growing stock on page 85, the following notes on treatment would apply to the second example given.

Supplementary fellings. Remove mature trees over pole crop within 10 years. In the open crop seed-bearers should be felled very gradually as regeneration takes place. Break up the soil in good seed years. Regeneration obtained now should be exploitable with the existing pole crop in the III or IV period. Thinnings: are required now over about 220 acres; from experience in an adjoining similar area the yield will be about 375 cubic feet per acre; grazing must be prohibited.

III. Collection of Statistical Data

(*a*) *Rates of Growth.*

Statistics regarding the girth (or diameter), height and volume increment and yield in merchantable timber of individual trees will be required both for fixing the rotation and regulating the yield. These will be obtained by one of the methods learnt under mensuration; but the time available for the preparation of a working plan will be insufficient to collect complete and accurate information under these heads and, unless previous investigations have been made on an extensive scale, the figures obtained can only be regarded as provisional. The same remark will apply to the measurement of temporary sample plots of different ages to determine crop increment in the case of regular woods.

(*b*) *Stocktaking.*

If yield tables are available and the quality and density of each compartment have been assessed when making the description of the compartments, then all that will remain to be done will be to determine as near as possible the mean age of the crop in the compartment, the volume of which it is required to estimate. If yield tables are not available and the woods are more or less even-aged, their contents may be obtained by means of sample plots or strip surveys; whether measurements are required over the whole area or only in the compartments which will be cut over during the working plan period will depend upon the method adopted to calculate the yield. In irregular forests trees will have to be enumerated by girth or diameter classes. The area over which these will have to be carried out will depend upon the silvicultural system employed and the method adopted to calculate the yield. In Selection Forests enumerations will be required over the whole,

or samples of the whole, area ; in other cases stocktaking in compartments allotted to the working plan period may suffice. Complete enumeration over a large area is a lengthy and laborious undertaking, particularly in mountainous country, and it may be only possible to enumerate in sample areas or strips (strip surveys), the latter being generally preferable in irregular forests. In backward countries, however, where cheap unskilled labour is available, complete enumeration may be feasible and not unduly expensive. In India sometimes illiterate coolies are employed, the diameter or girth classes being given distinctive colours on the tapes or callipers and the booking being done under similar colours in the notebook. Arrangements must be made so that a percentage of the enumerations can be checked, and therefore, where compartments are large, small enumeration sections, demarcated by natural or artificial boundaries, should be used. If the figures of previous stocktakings are available they will be compared with those now made in order to obtain information regarding the increment. Before the first stocktaking it is essential to consider carefully the most suitable limits of the size classes and the minimum size to be measured, so that the classification may be permanent and, consequently, the figures obtained comparable with those of future stocktakings.

CHAPTER III

The Working Plan Report

I. General

A good working plan will

(1). Be based on the most thorough knowledge obtainable of the tract to be dealt with.

(2). Avoid the attempt to obtain an impossible ideal, but aim at obtaining in the best manner possible the results required and no more (Broillard).

(3). Be concise, easy of reference and as exact and definite as possible in its prescriptions ; but will avoid limiting to an undesirable degree the discretion of the executive staff in certain directions, notably in silvicultural details.

(4). Recognize practical difficulties arising from such causes as marketing and transport problems, etc., and the limitations imposed by the technical abilities of the staff.

(5). (If the first plan for the area in question), provide a work of reference for subsequent generations containing all relevant information and a foundation on which all subsequent management will be built up.

It is not possible to prescribe a form of report to suit all cases, but the headings given in the following section have been drawn up with the idea of covering the ground as completely as possible. They are based on—and depart very little from—the Working Plan Headings drawn up by Mr. R. Bourne and published in the *Empire Forestry Journal*, Vol. 13, No. 2, of 1934. It is customary to divide a working plan into two parts ; Part I, dealing with the past and present, and Part II with the future. Only such figures should be given in the body of the plan as are necessary for understanding the context, all detailed figures should be relegated to the Appendices.

II. The Working Plan Report in Detail

Title. Name, author's name and date. Brief summary of the nature of the plan for easy reference. Thus for example :—

Working Plan for High Meadow Forests,
1920–30
by A. N. Blank, Deputy Surveyor,
Oak and Beech High Forest.

Rotation 150 years. Regular shelter-wood. Floating periodic block. Yield regulation by volume.

Reference to Preliminary Report and Correspondence.

Quote general recommendations as to policy and treatment and include correspondence relating to the preparation and sanction of the plan.

Table of Contents. Reference to pages or paragraphs, both of which should be numbered consecutively throughout.

PART I

Summary of facts on which Proposals are based.

Chapter I. Location and Ownership.

1. *Name, Situation.* Under situation enter name of county, civil district, forest division or other administrative unit.

2. *Distribution and Area.* Under distribution whether in one block or more, and whether compact or scattered. Area thus

Potentially productive—626 acres.

Permanently unproductive :—

Roads and rides	22 acres	
Grass-lands	56 ,,	
Waterways	5 ,,	
		83 acres
	Total ..	709 acres.

3. *Boundaries.* N, E, S, W; nature of boundaries and general state of boundary marks.

4. *Ownership and Legal Position.* Under " legal position " include a brief summary of rights and privileges.

A full detail of these will, if required, be given in an Appendix. Under " ownership," if state-owned, merely refer to the State Forest of ...., in the Title.

Chapter II. Local conditions.

1. *Configuration.* State whether flat, undulating, hilly, mountainous, and existence of precipitous unworkable ground. Give main drainage basins and watersheds and main aspects of hill slopes.

2. *Climate.* Give rainfall and snowfall, and their distribution, throughout the year; mention occurrence of frost and drought and prevailing winds.

3. *Rock and Soil.* Give the geological formations, and the chemical and physical properties of the soils, *e.g.*, acidity, depth, porosity, degree of moisture, structure. As regards chemical composition it is generally sufficient to mention any valuable mineral constituent in which the soil is markedly rich or deficient.

4. *Classification of Sites and Regions* resulting from the features dealt with in Sections* 1 *to* 3.

Chapter III. History.

1. *General History of the Forest.* Give a review of events which have influenced the species and crop forms in the past, past systems of silviculture and management, dates of previous working plans, if any.

2. *Injuries to which the Crops have been liable.*

(*a*). Animal agency, *e.g.*, insects, rabbits, squirrels, deer, cattle, etc.

(*b*). Plants, *e.g.*, fungi or other parasites, weeds, climbers.

(*c*). Climatic, *e.g.*, frost, snow, hail, wind, drought, floods.

(*d*). Other forms of injury, *e.g.*, fire, theft, damage by man, etc.

3. *Works of Improvement Undertaken.* Buildings, roads, draining, fixing sand dunes, hill slopes, etc. A list of such works, and the mileage of roads of different types, may usefully be given, together with their cost and adequacy or otherwise.

4. *Past Yields.* A summary only to be given, with references to the documents in which the details are recorded. Volume yields should be separated from figures of revenue and expenditure.

* Region = an association of sites.

Chapter IV. Ecological Considerations.

Forest Types. These will be referred to the regions and sites dealt with in Chapter II. Sample descriptions should be given of typical crops and their future discussed. A list of forest plants (which may be relegated to an Appendix), with their botanical and local names, should accompany this chapter, particular attention being directed to those of economic or ecological importance, *i.e.*, those which have a direct value, influence tree growth in any stage or act as site indicators.

Chapter V. Economic Considerations.

1. *Requirements of the Surrounding Population*. It is commonly recognized in the case of public forests that local residents, whether right-holders or not, have a first claim to consideration. Only domestic and agricultural requirements should be dealt with here. The requirements of local industries will be dealt with under the next heading.

2. *Markets and Marketable Products and Prices*. A bare statement giving a list of different products and the prices obtained will probably not be sufficient for the purpose of this section. Endeavour should be made correctly to interpret the information given, particularly past price fluctuations. Future proposals must be based on adequate study of the markets.

3. *Lines of Export, Methods of Exploitation and their Cost*. State whether the principal lines of export are by road, river or rail, etc., and the cost per unit; by what means the produce is extracted from the forest and the cost, whether the extraction and export is carried out by owner's or purchaser's agency.

Chapter VI. Statistics of Growth and Yield.

The procedure followed in the collection of data should be carefully described. Detailed figures will be given in an Appendix; but the figures evolved from these, indicating growth and yield at different ages, which form the basis of proposals for the future, must be given in the body of the plan. In place of figures, graphs may in many cases be used with advantage.

Part II

Future Management

Chapter I. Basis of Management. General.

1. *Objects of Management.* State briefly the objects of management as laid down by the owner.

2. *Division of the Area.*

(*a*). Into Working Circles.

(*b*). Into compartments and sub-compartments.

A working circle is an area under a working plan subject to one and the same silvicultural system and the same set of working prescriptions. Thus, if there be a marked difference in the prescriptions for different parts of the area, a separate working circle must be constituted for each such different part. These working circles will be designated by their principal characteristic, *e.g.*, High Forest W.C., Coppice W.C., Conifer W.C., Hardwood W.C., Shelter-Wood W.C., Selection W.C., Protection W.C., etc. The principles followed in the formation of compartments, the method of numbering, demarcating and indicating them on the ground, and the reasons for the formation of sub-compartments should be given.

Chapter II. Basis of Management. Special (for each Working Circle).

1. *Constitution.* In one compact block or scattered blocks. *

2. *Sub-division into Felling Series and Cutting Sections.* Separate felling series may be constituted for silvicultural reasons, *i.e.*, it may be considered undesirable to have unduly large felling areas in one place; or they may be formed for reasons of management, either to distribute works, or to supply different markets. For each felling series a separate calculation of the yield will have to be made, and it is undesirable to multiply them beyond the minimum required. Under regular systems it may be necessary, as explained in Part I, Chapter I, Section V, to form Cutting Sections in order to regulate the cuttings in some particular manner. Under the Selection

* If there is only one Working Circle, Chapters I and II are thrown together. If there is more than one W.C., each W.C. must be dealt with separately under Chapters II, III, IV and VI.

System, as indicated on p. 17, it is usual to divide the felling series into as many cutting sections as there are years in the Felling Cycle, and sometimes to calculate the yield for each cutting section separately.

3. *Species and Silvicultural System.* Give the reasons for choice of species, and, if more than one species is to be grown, state the proportion or distribution of the different species aimed at. If the silvicultural system is not a standard one it should be described.

4. *Rotation or Exploitable Size.* Give the reasons for the choice with an abstract of, or reference to, such figures (*vide* Part I, Chapter VI, of the W.P. Report) as are necessary to explain the same. If exploitable size is given, it should be stated whether the same is the minimum, maximum, or mean size of a first-class tree. If it is a maximum then all trees above this size will represent surplus growing stock.

Where the choice of rotation is affected by several considerations (*e.g.*, silvicultural, technical and financial, *vide* Part I, Chapter I, Section IV), each factor should be considered separately, in order that a logical conclusion may be arrived at, *vide* also remarks on the financial rotation and rotation of the highest income in Part III.

Chapter III. The Principal Fellings.

1. *General Working Scheme.* Describe the scheme resulting from the provisions of Chapters I and II of the Report, and indicate the influence of the scheme on the future welfare and yield of the forest. In order to show that the future of the forest is being adequately provided for, in so far as can be foreseen, it is desirable to show the situation, which should, in theory, result from the proposals at the end of certain periods and at the end of the first rotation.

2. *Special Plan for the Period.* Deal with the proposals for the working plan period only.

3. *Rules, or Guiding Principles for executing the fellings.* Refer to the silvicultural system, and make such further observations as are required to guide the executive staff in marking the fellings.

4. *Tabular Statement.* Detail the fellings to be carried out in the working plan period; this is generally given in an appendix.

Chapter IV. Subsidiary Fellings.

1. *Description.* Give rules or guiding principles for the execution of thinnings and any other operations which will produce a marketable yield. Operations, which it is not anticipated will produce a marketable yield, are generally dealt with under Chapter VI of the Report.

2. *Tabular Statement.* Generally in an appendix.

Chapter V. The Yield.

1. *Method of Estimating.* The results of enumeration surveys will have been dealt with in Part I, Chapter VI, of the Report. The method of using them to calculate the yield will now be given.

2. *Forecast of:*

(*a*). Final.
(*b*). Intermediate.
(*c*). Total.

3. *Distribution and Equalization of, by Years or Periods.* The annual possibility having been determined as above, it will be necessary to consider whether this is to be cut annually or whether it is more convenient to prescribe a periodic yield only, allowing of any convenient distribution of this over the years of the period.

Chapter VI. Cultural Operations.

Cleanings, Sowings, Planting, etc. Deal with each subject separately and describe the method of execution. Tabulate the prescriptions, generally in an appendix. Under this chapter are dealt with all the operations for the improvement of the crop, which are not anticipated to yield revenue.

Chapter VII. Miscellaneous Prescriptions.

1. *Forest Staff.* State what establishment will be necessary for the efficient carrying out of the working plan proposals, and compare it, in constitution and cost, with that at present existing.

2. *Protection.* State any special operations required to protect the forest from fire, etc., and estimate the cost.

3. *Roads and Buildings.* As above.

4. *Collection of Data.* Give necessary instructions for measuring and the upkeep of records of existing sample plots, for the formation of new ones, and for measurements and ring countings on individual trees.

5. *Control.* Prescribe the necessary forms of control (*vide* Chapter IV, p. 98).

6. *Revision.* Suggest when and to what extent revision of the plan will be necessary.

Chapter VIII. Financial Forecast.

This will be for the working plan period only. Give in detail the estimated annual expenditure on Establishments and Operations separately, similarly the revenue and consequent surplus or deficit.

Appendixes

It is impossible to give a list of appendixes required for every working plan, but the following are generally necessary :

1. *Description of Compartments and Sub-compartments.* See Part II, Chapter II, Section II of this volume.

2. *Distribution of Age Classes.* A tabular statement of compartments and sub-compartments by area under age classes. Required for visualizing the condition of the forest and for allotment of areas to periods of the rotation.

3. *Annual Summary of Prescriptions.* Tabulate the prescriptions for each year of the working plan period. If possible include all prescriptions in one table.

4. *Control Forms* (*vide* Chapter IV, p. 98). If convenient the annual control form may be included in (3).

5. *Results of Enumeration Survey.*

6. *Results of Ring Countings and Borings for Increment.*

7. *Record of Sample Plot Measurements.* Used for compiling yield tables.

8. *Maps.* It is necessary to distinguish between :

(*a*). The general topographical survey map required by executive officers to locate their forests, and

(*b*). Maps required to illustrate the nature of the crop, the working plan proposals and the fundamental properties of the locality and crop, on which these proposals are based.

The former may be the standard topographical survey map of the district with merely the forest, compartment, working

circle, etc., boundaries, and the numbers of boundary pillars marked thereon. In the case of large areas these maps will comprise several sheets, and will generally not be bound up with the working plan. Under (*b*) we have the working plan maps proper, and they should illustrate :—

(i) Regions and sites.
(ii) Nature of crops.
(iii) Working Plan prescriptions.

Under (i) a geological map may be included, but geology is seldom of sufficient importance to justify a separate map. If the recognition of sites has reached a sufficient degree of advancement, then this map may usefully show, by distinguishing colours, the sites resulting from the different factors of locality. Under (ii) a map, showing by different colours, or varying shades of the same colour, the distribution of age classes and species, and under (iii) a map showing the allotment of areas to working circles, felling series, or periods of the rotation. Maps serving purposes (ii) and (iii) can generally be combined into one map and in some cases all purposes can be served by a single map. This is achieved by using different ground colours to serve one purpose, different coloured boundaries to serve another, and so on. The maps must be on a sufficiently large scale to show clearly what is required, but large sheets are inconvenient and, as it is desirable to represent the whole area covered by a working plan on one sheet, an unnecessarily large scale should not be used.

CHAPTER IV

The Control of the Working Plan

It is not sufficient to prepare a working plan ; it is necessary also to see that its provisions are carried out. In order to ensure the latter, certain records must be maintained which will vary according to the requirements of the particular plan. Generally the following will be required in varying forms.

(1). Record of Changes.
(2). Control Forms for each Working Circle.
(3). Compartment Registers.
(4). Maps.

(1). *Record of Changes.* Show changes in area, *e.g.*, by sale, purchase, exchange, alteration of boundaries, etc., reference being quoted to the sanctioning authority. Sanctioned alterations in the prescriptions of the plan must also be recorded in this or another register.

(2). *Control Forms.* The prescriptions of the plans are entered on the left and the execution on the right. The form will vary according to the requirements of the particular plan ; the example on p. 100 will serve to show what is required.

(3). *Compartment Register.* The object of this is to give a continuous and complete history of each compartment. The number, area and description of each compartment (as given in Appendix I of the working plan) will be entered first, then the prescriptions of the plan in so far as they relate to the compartment in question, and finally year by year the progress of works prescribed and remarks regarding any other matters of importance affecting the compartment, thus :—

Prescriptions. Final fellings on regenerated portion of 10 acres, estimated yield 10,000 cubic feet. Planting oak in blanks

on 3 acres. Thinnings on 15 acres, estimated yield 5,000 cubic feet.

Year.	*Work done.*	*Fellings.*				*Culti-vation.*	*Remarks.*
		Final.		*Thinnings.*			
		Area.	*Yield.*	*Area.*	*Yield.*		
1928	Final fellings. Planting 2 yr. S. Pine.	4	3,000			1	
1929	Final fellings. Planting 2 yr. S. Pine.	6	7,500			3	10 acres on N. boundary burnt and last year's plants destroyed.
1932	Thinnings.			6	800		

(4). *Maps.* All alterations in area or boundaries and new roads, etc., will be immediately marked on the maps. Apart from this, maps may be used to record the progress of silvicultural operations or damage by fires, etc.

PROVISIONS OF WORKING PLAN.							RESULTS OF WORK DONE.						
Year		*Compartment.*	*Fellings (vol. in cubic feet or area in acres).*		*Cultivation.*	*Roads‡ (miles and chains, vide para.)*	*Fellings.*		*Cultivation.*	*Roads.*	*Excess*	*Deficit.*	*Remarks.*
of Working.	*of Prescription.*		*Final vide para.**	*Intermediate vide para.*	*(Acres, vide para.)*		*Final.*	*Intermediate.*					
			† Excess and Deficits from Previous Years.										
1930	1929	3		−50				50					
					Year's Prescriptions.								
1930	1930	5	500		3		500		3				
1930	1930	7		100				80				20	Due to shortage of labour.
1930	1930	Various				2··60				2··30			The road is completed, but on a shorter alignment.

Notes: * It is useful to refer to the para. of the W.P. dealing with the prescription in the column heading.
† 2. Excess and deficits will not be carried forward unless it is proposed to adjust them subsequently.
‡ 3. Where there are many prescriptions it may be desirable to maintain a separate control form for works.

PART III

FOREST VALUATION AND FINANCE

CHAPTER I

Introduction

The Effect of the Earning Power of Money on Forest Operations. Security. The Ruling Per Cent. Forest Capital. (Hiley's *Economics of Forestry*, pp. 90–104.)

Forest operations involve the employment of capital. Public borrowing in modern times, resulting in the establishment of fixed interest-bearing investments, has given a definite earning power to money so that the owner of capital, large or small, can obtain annually a small payment for its use without any equivalent employment of his own energies. Every forest operation and every forest product harvested implies the expenditure or receipt of money, which in its turn has a definite earning power, and it is necessary to consider the effect of this earning power on forest management.

It is obvious that the effect of the earning power of money is to make its use in enterprise unattractive unless the enterprise in question holds out a prospect of profit over and above this earning power. This proposition applies to any form of industrial investment, but its application to forest operations is special and peculiar, at least in the initiatory stages of the latter, owing to the long period which elapses between expenditure and the realization of income therefrom. It is clear that the latter will be debitable with the accumulated earnings of the money expended, or in other words that expenditure will accumulate at compound interest, and only when income exceeds the amount of this accumulation will any profit be realized. We see, therefore, that, unlike most investments,

an investment in forestry is a compound interest one, and this fact both complicates the financial problems with which we are concerned in forestry, and greatly increases the importance of the factor of the earning power of money in our calculations. The latter point is clear when we consider that at 2%, 4% and 6%, a capital sum will double itself in 35, 18 and 12 years respectively; or during an 80-year rotation an initial expenditure of £1 will, at the above percentages, amount to £4·88, £23·01 and £105·76 respectively. Even when a forest, giving a sustained yield, has been built up, the question of compound interest cannot be excluded altogether from consideration, since it exercises a great effect on the rotation, variations in which will cause corresponding variations in the amount of capital invested.

The earning power of money is not a fixed thing, but varies according to varying economic and political conditions. When these were comparatively stable at the end of the nineteenth and the beginning of the twentieth century, the rate at which the principal governments could borrow gave a fairly constant standard by which this earning power could be measured. Thus at that time in Great Britain, it would be about 2½%, in the principal European countries 3% and in India 4%. Since the Great War this rate, even in Great Britain, has fluctuated between 2¼% and 6%. It is, therefore, impossible to lay down any definite rate which should be applied to forest calculations. If money is borrowed, it is, of course, necessary to calculate with the rate not less than that actually paid; but, even in this case, a high initial rate may not have to be applied up to the time that income is realized: for a change in conditions may enable a loan to be raised at a lower rate, and thus the original loan may be repaid. The following considerations provide some justification for the exclusion of high rates of interest from forest calculations.

(1). A high interest rate does not represent the true earning power of money. In the long run borrowers can only afford to pay a small percentage of the amount borrowed for its use. If they have to pay more, default in some form or another will ensue. The truth of this is shown by recent history.

(2). There is no such thing as a safe long term investment outside forestry and, perhaps, insurance (on which the yield is very low). British Government loans occupy the highest

position. $2\frac{1}{2}\%$ Consols reached the price of £112 before the South African War; during the Great War they touched £43, so that an investor at the higher price, who had to sell out at the lower, would have lost over 60% of his capital.

(3). History shows that over a long period prices of commodities in terms of money tend to rise. The investor in forestry will benefit from this rise, investors who receive their income as a fixed sum of money will lose by it.

The first two arguments used above are based on the comparative security of forest investments. It is a well-recognized axiom in finance that the greater the security the lower the yield which will be acceptable. It is fair to apply this argument of greater security to any well-considered forest investment, where the risks are well spread, as in the case of extensive national forests in different parts of the country. Owing, however, to risks of fire, disease, etc., an investment in a single plantation, particularly if it is a coniferous one, must be regarded as speculative in so far as the investment is represented by expenditure on growing stock. The land itself gives a high degree of security.

The earning power of money is expressed as a per cent. of the amount borrowed, or rather as a rate per cent. per annum ~~per £100~~. This rate has been called by different authors "The General Per Cent." or the "Forest Per Cent." RULING PER CENT. seems a more accurate description of what is meant and will be used in this work. The term Forest Per Cent. more accurately expresses the rate per cent. compound interest at which the Forest Capital is actually working, as indicated by the increase in value between two periods (Schlich, Vol. III, Edition 5, p. 139). Thus if F be the 1st value, Fn be the value n years later, and the rate per cent. $= p_f$.

Then Fn is the amount of F in n years, working at p_f % compound interest, and the value of p_f may be found by logarithms from the formula

$$Fn = F \times 1{\cdot}0p^n_f \text{ (\textit{vide} Chapter III).}$$

Where the period n is the whole rotation, p_f is known as the MEAN ANNUAL FOREST PER CENT., or the FINANCIAL YIELD. Where n = 1 year, p_f is known as the Current Annual Forest Per Cent; since however, one year is too short a period for the calculation of increment, the average for a short period of

years is calculated, and p_f is then known as the INDICATING PER CENT.*

The subject of Forest Finance is mainly concerned with the effect of compound interest on capital increment, and one of these three percentages, Ruling Per Cent., Mean Annual Forest Per Cent., or Indicating Per Cent., is applied to most calculations; the last two percentages will be dealt with more fully in due course.

* *Note.*—Throughout this work the following abbreviations will be used: Ruling Per Cent. = p. Mean Annual Forest Per Cent. = $_{m}p_f$. Forest Per Cent. = p_f. Indicating Per Cent. = $_{c}p_f$.

CHAPTER II

A Summary of the Problems dealt with under Forest Valuation and Finance

(*Vide* also Chapman's *Forest Valuation*, Chap. IV.)

I. Valuation of Capital

The Capital consists of the Land, Growing Stock, Buildings, etc. This value may be expressed in the following different ways :—

(*a*). The Cost Value.
(*b*). The Sale Value.
(*c*). The Rental Value.
(*d*). The Expectation Value.

(*a*). *Cost Value.*

The amount paid at the time of purchase is the " *cost value* " of a property. This may be increased by expenditure on development which increases the capital value of the property. Normally such increases are a matter of simple addition. A forest property, however, represents a productive investment on which the returns may be delayed for many years, so that a long time elapses before either the capital invested in the original purchase begins to bear interest or the annual expenditure is balanced by the revenue. Under these circumstances both the original amount spent on purchase and subsequent expenditure on development, etc., accumulate at compound interest leading to a new " *cost value* " peculiar to forestry.

The determination of this cost value is useful for the valuation of immature plantations and for the purpose of estimating the profits which they will yield when felled, the latter being represented by the cost value when assessed less the anticipated sale value.

The *cost value* of a crop may be defined as *the total cost of the property to date plus accumulated compound interest charges*

less the value of any capital asset, where such value is independent of the crop.

Examples of capital assets having a value independent of the crop will be found in the land, permanent buildings, stores, live stock, etc., whilst expenditure on roads, drainage, etc., will generally be directly debitable to the crop.

Thus for example :—

Dr.	£	*Cr.*	£
Purchase money plus compound interest charges	a	Land valued at cost ..	c
Subsequent expenditure less revenue plus c.i. charges	b	Buildings at cost less depreciation charges ..	d
		Stores ditto	e
		Cost value of the crop ..	x
Total	£A	Total	£A

or $x = (a + b) - (c + d + e)$

(*b*). *Sale Value.*

A sale establishes a new recorded or book value of a property and forms a convenient starting point from which to make subsequent valuations (Chapman). Whether or not it represents the intrinsic value, depends on how the sale price has been arrived at.

(*c*). *Rental or Income Value.*

When a forest is being worked for a sustained yield, so that a continuous net income is realized, this income (or the average net income over a period of years) may provide the most reliable indication of its value. Accuracy is a relative term in most forest calculations, and the net apparent income would not be the net real income except in the case of a normal forest, which is probably non-existent. In practice, the annual real income is usually either increased by a partial realization of capital, or decreased by a partial saving of the same to increase the capital; for this is the effect in any forest in which the exact increment is not being cut. Further it is important to note that the rental value will not give an accurate indication

of the real capital value unless the forest is being worked on a rotation which, having regard to all the circumstances, may be regarded as the correct one ; for it is clear, from what has been said in Chapter I, that the value of the capital depends on the rotation adopted, and only when the latter is correct will the income correctly indicate the value of the former. This point is dealt with more fully later under Financial Rotation and Rotation of the Highest Income. However, where investigation into value is keenest, as in sale and purchase, the net income of a going concern is in common commercial practice the basis of valuation and would be accepted by the purchaser subject to an investigation into past management. To ascertain the Capital Value from the Income Value it is necessary to apply a value to p, then

$$\text{Capital} = \frac{100}{p} \times \text{Income.}$$

This is frequently expressed by saying that a property is worth so many years' purchase (of Rental).

Thus, if $p = 5\%$, the property is worth 20 years' purchase, if 4%, 25 years' purchase, if $2\frac{1}{2}\%$, 40 years' purchase, and so on. *E.g.*, if £25 is the net income or rental and $p = 5\%$, the capital value is $\frac{100}{5}$ = 20 years' purchase = £20 × 25 = £500.

(*d*). *The Expectation Value.*

This, as its name implies, is a valuation based on future anticipated net income calculated on the assumed productivity of the investment. Actually it is the present value (*i.e.*, future values discounted to the present time) of all future items of income less the present value of all future items of expenditure. In forest operations its application is generally to the soil, mainly in connection with determining the financial prospects of afforestation and the most profitable rotations. It may on occasion be necessary to determine the Expectation Value of the Growing Stock in compensation cases, where immature woods are destroyed or damaged, or have to be acquired. Methods of determining the Expectation Value are dealt with in Chapter IV.

II. Productivity of Capital

Having valued the capital, it may be necessary to determine its productivity, or activity as it is called, at different rotations. The indicating per cent. referred to in Chapter I is a useful indicator of this activity and the method of ascertaining it is dealt with in Chapter IV, Section IX ; but generally a knowledge of the rotation at which the capital reaches its maximum productivity is required. This rotation is known as the FINANCIAL ROTATION. It may be defined as the rotation which gives the highest net return on capital and is identical with

(*a*). The rotation giving the highest soil expectation value (*vide* Chapter IV, Section VI), and

(*b*). The rotation giving the maximum mean annual forest per cent. (*vide* Chapter IV, Section VII).

It must not be confused with the rotations which give

(*c*). The largest profit (Chapter IV, Section VI), or

(*d*). The maximum net income (Chapter IV, Section X),

since neither of these take into account the differences in the amount of capital employed at different stages.

CHAPTER III

FORMULÆ FOR CALCULATING COMPOUND INTEREST CHARGES

IN order to avoid constant re-calculation a set of formulæ have been evolved to cover most of the calculations required in forest finance. They are as follows :—

I. Amount or Future Value

Value of capital Co bearing interest at p% in n years.

$$Cn = Co \times 1{\cdot}0p^n \quad . \quad . \quad . \quad . \qquad \textit{Formula I.}$$

Proof.—Since the interest on £1 for 1 year $= \frac{p}{100} = .0p$

$\therefore$ in 1 year £1 amounts to $1 + {\cdot}0p = 1{\cdot}0p$

and in 1 year £1·0p amounts to $\frac{1{\cdot}0p \times 1{\cdot}0p}{1} = 1{\cdot}0p^2$

so that at the end of the 2nd year £1 amounts to £$1{\cdot}0p^2$
and similarly at the end of n years £1 amounts to $1{\cdot}0p^n$

and £Co to £$Co \times 1{\cdot}0p^n$

Values of $1{\cdot}0p^n$ for different values of p and n can be worked out by logarithms and a table covering most of the values will be found in Appendix II. For examples of use see p. 118, where the formula is used to obtain future values of cost of land and revenue from thinnings.

II. Discount or Present Value

In the above formula Co is the present value of Cn to be realized n years hence. Therefore with the value of Cn given, the formula is reversed and we have

$$*Co = \frac{Cn}{1{\cdot}0p^n} \quad . \quad . \quad . \quad . \qquad \textit{Formula II.}$$

For example of use see p. 136, where the formula is applied to obtain the present value of the final yield.

* From values of $1{\cdot}0p^n$ given in the Appendix this and the following formulæ can be solved by simple multiplication and division, but time may be saved by using the multiplying factors given by Schlich in Appendix III, Vol. III.

III. Summation of Rentals

A knowledge of the meaning of geometric progression and the method of its summation is required.

Quantities are said to be in geometric progression when each quantity = product of the preceding quantity and some constant factor, called the common ratio, *e.g.*,

3, 6 ($= 3 \times 2$), 12 ($= 3 \times 2^2$), 24 ($= 3 \times 2^3$) is a geometrical progression having a common ratio 2.

$$\text{Its sum} = \frac{\text{Product of 1st term and the common ratio to the power of the number of terms minus 1}}{\text{common ratio minus 1}}$$

i.e., in the above case $\frac{3(2^4 - 1)}{2 - 1} = 45$

A geometrical progression may be expressed algebraically thus

$$a + ar + ar^2 + ar^3 + \ldots ar^{n-1}$$

and its sum as $S = a\frac{(r^n - 1)}{r - 1}$

This is the formula for an ascending series, where $r > 1$. Should $r < 1$, then the formula will be for a descending series and will be reversed; thus

$$S = a\frac{(1 - r^n)}{1 - r}$$

If n is infinity then $S = \frac{a}{1 - r}$

(*a*). *Future Values.*

A rental R becomes due for the first time after m years, and is repeated altogether n times at intervals of m years. Its capital value after $m \times n$ years will be

$$Cmn = \frac{R\,(1{\cdot}op^{mn} - 1)}{1{\cdot}op^{m} - 1} \quad \ldots\ldots \quad \textit{Formula III.}$$

Proof.—The Rental R is realized in the m*th*, 2m*th*, 3m*th* . . . . . . (nm − m)*th* and nm*th* years.

Working back from the nm*th* year so as to obtain an ascending series the values to be summed will be

R realized in the nm^{th} year has a value in the nm*th* year of R
R „ „ „ $(nm - m)th = m\,(n - 1)th$ year has a value in the nm^{th} year of R $\times$ $1{\cdot}op^{m}$ (from Formula I)
R „ „ „ $(nm - 2m)th = m\,(n - 2)th$ year has a value in the nm^{th} year of R $\times$ $1{\cdot}op^{2m}$
etc.
R „ „ „ m*th* year has a value in the nm^{th} year of R $\times$ $1{\cdot}op^{(n-1)m}$

The sum of this series is that of a geometrical progression of which the first term is R, the common ratio $1{\cdot}op^{m}$ and the number of terms n.

Hence the sum $= \dfrac{R\,(1{\cdot}op^{mn} - 1)}{1{\cdot}op^{m} - 1}$

Should the rental be due *each* year altogether *n* times the formula evolved in a similar manner will be

$$Cn = \frac{R\,(1{\cdot}op^{n} - 1)}{0{\cdot}op} \quad . \; . \; . \; . \; . \quad \textit{Formula IV.}$$

This may be obtained direct from Formula III by introducing $m = 1$. For example of use see p. 118, where the formula is applied to obtain the future value of annual charges.

(*b*). *Present Values.*

A rental R becomes due for the first time after m years and is repeated n times after intervals of m years; its present value is,

$$Co = \frac{R\,(1{\cdot}op^{mn} - 1)}{1{\cdot}op^{mn}\,(1{\cdot}op^{m} - 1)} \quad . \; . \; . \; . \quad \textit{Formula V.}$$

Proof.—It has already been shown (Formula II, p. 109) that present values may be obtained from future values by dividing the latter by $1{\cdot}op^{x}$ where x = total number of years involved.

Thus Formula V $= \dfrac{\text{Formula III}}{1{\cdot}op^{mn}} = \dfrac{R\,(1{\cdot}op^{mn} - 1)}{(1{\cdot}op^{m} - 1)\,1{\cdot}op^{mn}}.$

If instead of being due after m years the rental is due each year altogether n times then the formula becomes

$$Co = \frac{R\,(1{\cdot}op^{n} - 1)}{1{\cdot}op^{n} \times {\cdot}op} \quad . \; . \; . \; . \quad \textit{Formula VI.}$$

Proof.—Similar to that for Formula V. Divide Formula IV by $1{\cdot}op^n$, or put $m = 1$ in Formula V.

For example of use see p. 136, where the formula is applied to obtaining the present value of annual costs.

If the rental is due at the end of each year for ever, then the formula becomes

$$Co = \frac{R}{{\cdot}op} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \textit{Formula VII.}$$

Proof.—From Formula II the series will be

$$\frac{R}{1{\cdot}op} + \frac{R}{1{\cdot}op^2} + \ldots \frac{R}{1{\cdot}op\,\infty}$$

The common ratio $= \frac{1}{1{\cdot}op}$ and, since the number of terms is infinite, the sum of this geometrical descending series will be

$$\frac{\frac{R}{1{\cdot}op}}{1 - \frac{1}{1{\cdot}op}} = \frac{R}{1{\cdot}op} \times \frac{1{\cdot}op}{1{\cdot}op - 1} = \frac{R}{{\cdot}op}$$

For example of use see p. 121, where the formula is applied to obtain the present value of annual expenses due each year in perpetuity.

Note.—The present value of a rental, due at the end of each year for ever is, of course, identical with the capital which will give that rental (yield) annually, *i.e.*, present value of R due at the end of each year for ever $= \frac{R}{{\cdot}op}$ has the same meaning as

$$\text{Capital} = \frac{100 \times \text{income}}{p} = \frac{\text{income.}}{{\cdot}op}$$

If instead of every year, the rental is due after n years and again every n years for ever, the formula becomes

$$Co = \frac{R}{1{\cdot}op^n - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \textit{Formula VIII.}$$

Proof.—Similar to the above, the series is $\frac{R}{1{\cdot}op^n} + \frac{R}{1{\cdot}op^{2n}} \ldots$ etc. For example of use see p. 121, where the formula is applied to obtain the present value of final yields in successive rotations in perpetuity.

If the rental is due after m years and again every n years for ever, the formula becomes

$$Co = \frac{R \times 1{\cdot}op^{n-m}}{1{\cdot}op^{n} - 1} \quad . \quad . \quad . \quad . \quad \textit{Formula IX.}$$

This may be considered as a combination of I and VIII, for the value in the year n of R, from formula I $= R \times 1{\cdot}op^{n-m}$, and the present value of $R \times 1{\cdot}op^{n-m}$ received in the year n and at intervals of n years in perpetuity, from Formula VIII $= \frac{R \times 1{\cdot}op^{n-m}}{1{\cdot}op^{n} - 1}$.

For example of use see p. 121, where the formula is applied to obtain the present value of thinnings, occurring at regular intervals for successive rotations in perpetuity.

If the rental is due now, and then every n years for ever, the formula becomes

$$Co = \frac{R \times 1{\cdot}op^{n}}{1{\cdot}op^{n} - 1} \quad . \quad . \quad . \quad . \quad . \quad \textit{Formula X.}$$

This again is a combination of I and VIII.

For example of use see p. 121, where the formula is applied to obtain the present value of costs of formation occurring now and at the commencement of each rotation in perpetuity.

IV. Conversion of an Intermittent into an Annual Rental

The conversion is effected by multiplying the *capital value* of the intermittent rental by ·op. That this is so is clear from Formula VII. For, since

$$C = \frac{R}{{\cdot}op}, \quad \therefore R = C \times {\cdot}op$$

Formulæ VIII, IX and X represent the capital values of intermittent rentals, and they may be converted into annual rentals in this manner; thus, a thinning of Ta occurring in the year a in successive rotations of r years in perpetuity will be equivalent to a yearly rental of

$$\frac{Ta \times 1{\cdot}op^{r-a}}{1{\cdot}op^{r} - 1} \text{ (from Formula IX) } \times {\cdot}op.$$

CHAPTER IV

Solution of Problems Relating to the Valuation and Productivity of Forest Capital

I. *Money Yield Tables*

It will be impossible to make any commencement with the solution of financial problems relating to the future unless we have the means of making some estimate of the value of the produce which will be marketed during the life of the wood. For this purpose it is usual to prepare *Money Yield Tables.* The method of preparing volume tables will have been learnt under forest mensuration, and money yield tables are prepared by substituting values for volumes in these. For further information regarding the preparation of money yield tables reference may be made to Hiley's *Economics of Forestry*, and the following abbreviated example of a table is taken from his work and will be used to illustrate the financial problems in the following chapters.

Before proceeding, however, a word of warning is perhaps necessary regarding the preparation of these tables. Since important calculations, seriously affecting forest policy, may be based on them, the reliability of the values inserted should be most carefully considered. Perhaps the main danger to be guarded against is overweighting values in favour of timber of small dimensions, such as that obtained from thinnings and the final yields on short rotations, especially in the case of conifers. High yields from poles and pit props make forestry a more attractive financial proposition and indicate short rotations. But the market for such timber is a much narrower one than that for timber fit for the sawmill, and, should short rotations be generally adopted on account of the optimistic estimates of values for small timber given in

yield tables, it is not unlikely that markets would become flooded with such timber, in which case the calculations based on these tables would prove to be erroneous.

MONEY YIELD TABLE FOR EUROPEAN LARCH

Quality II

Age.		*Thinnings.* £ (Ta) per acre.		*Final Yield.* £ (Yr) per acre.
15	..	2·5	..	
20	..	2·5	..	16·9
25	..	5·2	..	40·7
30	..	5·2	..	63·4
35	..	3·8	..	85·7
40	..	5·2	..	111·0
45	..	6·7	..	137·0
50	..	8·4	..	160·0
55	..	9·2	..	183·0
60	..	9·8	..	205·0
65	..	10·5	..	227·0
70	..	11·7	..	249·0

II. Capital Accounts and Cost Values

Where a Capital Account is drawn up year by year, it will contain the data of costs, revenue and assets, referred to in Chapter II, and will directly indicate the Cost Value of an existing Growing Stock.

Example I shows an abridged capital account maintained by the British Forestry Commission.

Example I.

Capital Account for the year ending 30th September, 1927.

Dr. *Liabilities.*			*Cr.* *Assets.*	
1. Balance brought forward from previous year		1,721,772	4. Land valued at cost	269,949
2. Expenditure of the year	412,090		5. Buildings, valued at cost, less depreciation	81,992
Less Income of the year	50,283	361,807	6. Stores	7,172
		2,083,579	7. Farm stock valued at	15,662
3. Interest charges ...		98,884	8. Balance, representing growing timber	1,807,728
Total		2,182,463	Total	2,182,463

The following is the explanation of this account :—

Item I. The debit balance brought forward from 1926 represents the cost value of the woods at the end of 1926. Similarly *Item* 8, the amount required to balance the account, *i.e.*, the amount required to raise the total of the Cr. side of the account to the total of the Dr. side, is the cost value of the woods at the end of 1927, and will be the opening Dr. balance (*Item* 1) in the account for 1928.

Item 3. Interest charges. For the purpose of this example, we may assume that these represent the actual amount, which was paid on money borrowed during past years and during the present year, and remaining outstanding at the end of the year, *i.e.*, on *Item* 2, £2,083,579. The rate of interest therefore amounts to

$$\frac{98{,}884 \times 100}{2{,}083{,}579} = 4{\cdot}87\% \text{ per annum.}$$

The value of roads in the Forestry Commission's account is included in *Item* 8 on the principle that these, unlike buildings, etc., have no value apart from the crops which they serve.

If this account were for a single plantation, *Item* 8 would, when the crop was mature, give the real cost of production of the final yield, and, if equal to the sale value, indicate that the plantation had just earned the interest on the borrowed money

and no further profit had accrued. Similarly, any excess of the sale value over *Item* 8 would indicate a profit over interest charges, and any deficit a loss or failure to earn these interest charges.

An account, such as the above, is of great value in the case of newly formed or acquired forests. It can be commenced at any period in the history of a forest property provided it is possible to assign a capital value to the same to serve as the opening Dr. balance. The following example shows how the capital account would be maintained for a forest property just purchased and already productive.

Example 2.

Capital Account, first year of a newly purchased forest property.

Dr.	£	*Cr.*	£
1. Cost	10,000	4. Value of land and G.S. at cost	9,000
2. Interest Charges at 4%	400	5. Value of buildings, etc., at cost less depreciation ...	960
3. Balance profit ...	260	6. Income ... £800 Less expenditure ... £100	700
Total ...	10,660	Total ...	10,660

III. Formulæ for Calculating the Cost Value of the Growing Stock (mGc) and Profits of Unit Woods

It has been shown above how the cost of the G.S., and profits of an existing wood can be ascertained from a capital account, and it will now be demonstrated how the capital account system can be used for the evolution of a general formula which may be used to determine the cost value of the G.S. at some future date, provided the items of probable revenue and expenditure are known. In addition to the information given in the money yield table in Section I the following will be required :

Cost of land	.. ..	Sc
Cost of formation	.. ..	C
Annual charges	.. ..	e

There may, of course, be other items of revenue and expenditure in addition to the above, but, if so, they will be dealt with in the same manner; *e.g.*, the value of receipts from minor produce would be obtained from the same formula as thinnings, if intermittent, and as annual charges if annual.

Example 3.

Estimate of the Capital Account in the 45*th year of a unit acre.*
Cost of land Sc = £5; Cost of Planting C = £10.
Annual charges e = £·6 (12s.); Yield from Money Yield Table on p. 115.
Interest charges 4%.

Dr.		*Cr.*	
1. Land at £5 = 5 × 5·8412 ...	£29·206	5. Land at cost	£5
2. Planting at £10 = 10 × 5·8412	£58·412	6. Balance, cost of crop aged 45 years ...	£107·749
3. Charges at £·6 × 121·025 ...	£72·615		
	£160·233		
4. Revenue from thinnings:			
2·5 × 3·2434 = 8·109			
2·5 × 2·6658 = 6·664			
5·2 × 2·1911 = 11·394			
5·2 × 1·8009 = 9·365			
3·8 × 1·4802 = 5·625			
5·2 × 1·2167 = 6·327			
	£47·484		
Net Total ...	£112·749	Total ...	£112·749

It is clear that the accounts in Examples 1 and 3 are similar, but differently expressed. The difference lies in the fact that the former has been kept up-to-date year by year and the latter is assumed to be prepared for the year 45 from available data; this being so, interest charges in the latter are separately calculated for each item for the whole period of 45 years.

Thus the cost of land, originally £5, has increased at 4% and in the 45th year amounts to £5 $\times 1{\cdot}04^{45}$ (formula I, Chapter III). From the table in Appendix II $1{\cdot}04^{45} = 5{\cdot}8412$; planting charges are similarly dealt with. Annual charges (*vide* Formula IV) $= 0{\cdot}6 \times \frac{1{\cdot}04^{45} - 1}{{\cdot}04}$. From the yield table the value of thinnings in the 15th year is £2·5 and their value in the 45th year, *i.e.*, 30 years later, is $2{\cdot}5 \times 1{\cdot}04^{30}$ (Formula I). The other thinnings are calculated similarly. On the Cr. side

are assets, the land at cost and the cost value of the crop (45 Gc) = £107·749, *i.e.*, the amount required to make the account balance.

Examples 1 and 3 are both capital accounts for undertakings in which the final yields have not yet been received and in which there are as yet no profits, consequently the amount on the Dr. side, required to balance the account, is necessarily the cost of the crop to date. This is in contrast to Example 2, which is for an undertaking already profitable.

If in the 45th year the crop is cut down and sold, receipts (*vide* yield table p. 115) will be £13~~6~~7 and the profit = Yr − mGc = £137 − £107·749 = £29·251.

From the above arithmetical example the equation for the cost value of the growing stock expressed in standard symbols can be evolved. Thus :

Example 4.

Estimate of the capital account in the m*th* year of a unit acre, expressed in standard symbols.

Dr.	*Cr.*
1. $Sc \times 1{\cdot}0p^m$	5. Sc
2. $C \times 1{\cdot}0p^m$	6. mGc
3. $e \times \dfrac{1{\cdot}0p^m - 1}{{\cdot}0p}$	
4. $-\Sigma Ta \times 1{\cdot}0p^{m-a}$	

By addition

$$Sc \times 1{\cdot}0p^m + C \times 1{\cdot}0p^m + e \times \frac{1{\cdot}0p^m - 1}{{\cdot}0p} - \Sigma Ta \times 1{\cdot}0p^{m-a} = Sc + mGc.$$

Now $\quad Sc \times 1{\cdot}0p^m - Sc = Sc\,(1{\cdot}0p^m - 1),$

and $\quad \dfrac{e}{{\cdot}0p}$ may be written as E,

so the equation reads :

$$mGc = Sc\,(1{\cdot}0p^m - 1) + E\,(1{\cdot}0p^m - 1) + C \times 1{\cdot}0p^m - \Sigma Ta \times 1{\cdot}0p^{m-a}$$

$$\text{or } = (Sc + E)\,(1{\cdot}0p^m - 1) + C \times 1{\cdot}0p^m - \Sigma Ta \times 1{\cdot}0p^{m-a}$$

The above is the formula for obtaining the cost value of the Growing Stock; and if the wood be cut down and sold the profit will be Yr − mGc.

IV. Expectation Values of the Soil based on Values of Unit Woods

The meaning of the term expectation value has been given in Chapter II. In the case of the soil we may refer to it as the "expected productive value" (Sc), and it is clear that, if there be no profit and no loss, then this value will be exactly equal to the cost value of the soil, *i.e.*, Se = Sc.

Likewise, in the formula given above for calculating mGc, it is clear that, if the cost value of the crop in any year is exactly equal to the final yield in that year, *i.e.*, if mGc = Yr, there will be no profit or loss.

Since this is so we are able to evolve the formula for Se direct from that for mGc by placing

Se = Sc and mGc = Yr and, since we are dealing with a rotation, substituting r for m, thus:—

from

$$mGc = Se\,(1{\cdot}0p^{m}-1) + E\,(1{\cdot}0p^{m} - 1) + C \times 1{\cdot}0p^{m} - \Sigma Ta \times 1{\cdot}0p^{m-a}$$

we obtain

$$Yr = Se\,(1{\cdot}0p^{r} - 1) + E\,(1{\cdot}0p^{r} - 1) + C \times 1{\cdot}0p^{r} - \Sigma Ta \times 1{\cdot}0p^{r-a}$$

or

$$Se\,(1{\cdot}0p^{r} - 1) = Yr + \Sigma Ta \times 1{\cdot}0p^{r-a} - C \times 1{\cdot}0p^{r} - E\,(1{\cdot}0p^{r} - 1)$$

i.e.,
$$Se = \frac{Yr + \Sigma Ta \times 1{\cdot}0p^{r-a} - C \times 1{\cdot}0p^{r}}{1{\cdot}0p^{r} - 1} - E.$$

This is known as FAUSTMANN'S FORMULA.

It may be evolved independently of the formula for mGc. If we consider the definition of Se, *i.e.*, "The present value of all future income less the present value of all future expenditure," and remember that the items of income and expenditure

are assumed to occur at the same times during each rotation in perpetuity, its evolution will be easy. Thus :—

Item.	*Value at end of 1st rotation, i.e., in year "r."*	*Present value if occurring after "r" years in perpetuity (from Formula VIII, Chapter III).*	
Yr	Yr	$\frac{Yr}{1{\cdot}0p^r - 1}$	1
Ta	$Ta \times 1{\cdot}0p^{r-a}$ (from Formula I)	$\frac{Ta \times 1{\cdot}0p^{r-a}}{1{\cdot}0p^r - 1}$	2
C	$C \times 1{\cdot}0p^r$	$\frac{C \times 1{\cdot}0p^r}{1{\cdot}0p^r - 1}$	3
		Present value if occurring at the end of each year in perpetuity (Formula VII).	
e		$\frac{e}{{\cdot}0p}$	4

$$Se = 1 + 2 - 3 - 4$$

Example: Using the money yield table on p. 115 and assuming that the costs of formation are £10 per acre and the annual expenses 12s. per acre, and that money is borrowed at 4%.

Calculate the expectation value of the soil per acre based on growing II Quality Larch on a rotation of 30 years.

$$Se = \frac{63{\cdot}4 + 2{\cdot}5 \times 1{\cdot}04^{15} + 2{\cdot}5 \times 1{\cdot}04^{10} + 5{\cdot}2 \times 1{\cdot}04^{5} - 10 \times 1{\cdot}04^{30}}{1{\cdot}04^{30} - 1} - \frac{{\cdot}6}{{\cdot}04}$$

$$= \frac{63{\cdot}4 + 4{\cdot}502 + 3{\cdot}700 + 6{\cdot}328 - 32{\cdot}43}{3{\cdot}243 - 1} - 15$$

$$= 20{\cdot}1 - 15 = £5{\cdot}1$$

V. *Profits*

In Example 4 (p. 120) it has been shown that the profits during any one rotation are

$P = Yr - mGc$ . . . . *Formula (a).*

Expressed in terms of soil values this is equivalent to

$$P = (Se - Sc) \times (1{\cdot}0p^r - 1) \quad . \quad . \quad . \quad \textit{Formula (b)}.$$

Proof.—From Faustmann's Formula.

$$Yr = Se\,(1{\cdot}0p^r - 1) + \frac{e}{{\cdot}0p}\,(1{\cdot}0p^r - 1) + C \times 1{\cdot}0p^r - Ta \times 1{\cdot}0p^{r-a}$$

and from the equation on p. 119 substituting r for m

$$mGc = Sc\,(1{\cdot}0p^r - 1) + \frac{e}{{\cdot}0p}\,(1{\cdot}0p^r - 1) + C \times 1{\cdot}0p^r - Ta \times 1{\cdot}0p^{r-a}.$$

Hence by subtraction the above value is obtained for P.

If the profit be calculated for a series of similar rotations in perpetuity then the present value of the profits in the year 0 becomes (from Formula VIII)

$$P = \frac{(Se - Sc)\,(1{\cdot}0p^r - 1)}{1{\cdot}0p^r - 1}$$

$$= Se - Sc \quad . \quad . \quad . \quad . \quad . \quad . \quad \textit{Formula (c)}.$$

VI. The Financial Rotation in Relation to Profits, Sc, Se and p.

The determination of possible profits is of importance in enabling a decision to be taken whether or not to invest, but a statement of financial results in terms of profits does not give a true expression of profitableness. A comparison of the advantages of different investments can only be made by comparing the real earnings of each, that is, the rate of interest earned in each case on the invested capital. In forestry a choice of rotations is equivalent to a choice of investments, and formulæ *a* and *b* above will not assist us in making the choice. To illustrate this we may refer to Table I below, in which the profits at different rotations have been calculated for soil costs of £11·05 and £5 per acre, and to Table II, in which Se has been determined for different rotations and different values of p. In both cases the money yield table already given for II quality larch on p. 115 is used; the cost of formation is taken at £10 per acre and annual expenses at 12s. per acre.

TABLE I

p = 4%

	Sc = £11·05			Sc = £5·00		
r	Yr	mGc	P ($\pm$ Yr $\mp$ mGc)	mGc	P	$\frac{P}{1{\cdot}0p^r}$ *i.e.*, Present value of P
	£	£	£	£	£	£
20	16·9	49·89	− 32·99	42·69	− 25·70	
25	40·7	63·32	− 22·62	55·25	− 11·55	
30	63·4	76·33	− 12·93	62·77	0·63	0·19
35	85·7	92·20	− 6·05	74·40	11·30	2·86
40	110·0	113·13	− 3·13	90·15	19·85	4·13
45	137·0	137·00	*Nil*	107·75	29·25	*5·01*
50	160·0	164·21	− 4·12	127·29	32·71	4·58
55	183·0	195·21	− 12·21	148·99	34·01	3·93
60	205·0	241·05	− 36·05	185·51	21·49	2·04

TABLE II

(from Hiley's *Economics of Forestry*, Table XXXII)

SOIL EXPECTATION VALUES

r	p = 2% £	p = 3% £	p = 4% £	p = 5% £	p = 6% £
25	17·1	3·8	−2·5	−6·2	−8·1
30	40·9	16·7	5·1	−1·1	−5·0
35	54·8	23·6	8·8	0·8	*−4·2*
40	64·5	27·6	10·5	*1·2*	*−4·2*
45	71·8	30·0	*11·1*	*1·2*	−4·7
50	75·0	*30·4*	10·4	0·0	−5·7
55	77·3	30·2	9·5	−1·0	−6·6
60	*78·5*	29·2	8·3	−2·0	−7·5
70	77·5				

From Table I we see that, with Sc = £5, the profit at the end of a 45-year rotation is £29·25, and at the end of a 55-year rotation it is £34·01. Yet the 45-year rotation is the more profitable; for, with p = 4%, £29·25 in the 10 years between 45 and 55 years would amount to £29·25 × $1{\cdot}04^{10}$ = £43·29. This shows that, during the extension of the rotation from 45 to 55 years, the capital is not earning 4% and, if money has to be borrowed at this rate, there will be a loss. If we wish to use profits to compare financial results we must discount them all

to the same time, as has been done in the final column of Table I, where the profits for each rotation, with Sc = £5, are discounted to the year "o." The highest discounted profit is obtained with a rotation of 45 years, and this is the *Financial Rotation*.

The figures in Table II are determined from Faustmann's formula. These Se values correctly indicate the financial rotation for any given value of p, that rotation which gives the highest Se being the financial rotation. This is the case independent of whether the rotation yields a profit or loss. At 6% the financial rotation is 35, though with Sc = £5 this would give a loss of £4·2 + £5 = £9·2. It may be said, therefore, that the financial rotation is that which gives the highest value for Se − Sc, if positive, or the lowest value if negative.

These two tables bring out the following important points :—

(1). Profits depend largely on purchasing the land cheaply. Table I shows that, with the data given, there can be no profit if Sc exceeds £11·05.

(2). The financial rotation is independent of soil cost. In both tables it will be seen that with p = 4% the financial rotation is always 45 years.

N.B.—This statement regarding the financial rotation only holds good where the value of p is fixed, *vide* the following section on the forest per cent. in relation to the financial rotation.

(3). The rate of interest charged "p" is the prime factor affecting the financial rotation, and, *ceteris paribus*, the higher the rate the lower the rotation. From Table II we see that at 2% the financial rotation is 60 years and at 5% about 42 years.

(4). The rate of interest charged is the prime factor affecting the possibility of profitable working. Good agricultural land can be purchased at £25 an acre and, at 3%, it will be seen that (assuming the correctness of the money yield table) there would at this price be a saving on soil cost of £5·4 ; whereas, at 6%, we could not afford to plant if we obtained the land for nothing.

It is obvious that the Expectation Value of the soil is a value which exists only in relation to the particular species grown. If the species is changed, the final and intermediate volume yields and their values will also change.

VII. The Financial Rotation in Relation to the Financial Yield (mpf)

In the previous sections it has been assumed that the money invested in forestry has been borrowed at a fixed rate of interest "p," so that any surplus obtained after earning this rate of interest represented profits "P." Another method of determining the profitableness of a forest undertaking would be to calculate the rate of interest "p" (*vide* Chapter I) which it is actually earning. In this case mpf will include both "p" and "P." It is also clear from Sections III and IV of this Chapter that, if Se = Sc, then "P" vanishes and only "p" is earned. Therefore, if we take Faustmann's formula for calculating the value of Se, and placing Se = Sc, substitute the latter for the former, we shall have an equation

$$\text{Sc} = \frac{\text{Yr} + \Sigma\text{Ta} \times 1{\cdot}0\text{p}^{r-a} - \text{C} \times 1{\cdot}0\text{p}^{r}}{1{\cdot}0\text{p}^{r} - 1} - \frac{\text{e}}{0{\cdot}0\text{p}}$$

in which "P" is eliminated and p = mpf. What we now require to determine from the above equation is the value of p (now mpf), when the values of all other terms in the equation are known.

The equation, however, is not directly solvable, and we can only solve it by inserting trial values of p for known values of S. This method was first evolved by Schlich in 1904 (*vide* Schlich, Vol. III, Vth Ed., p. 142), and is carried out by Faustmann's Formula for varying rotations and values of p as has been done in Table II*, p. 123. The values of Se are then considered as values of Sc, and, for any one rotation, are plotted in a graph as ordinates over the per cents. as abscissæ, as has been done in Fig. 16 for II Quality Larch for rotations of 40 and 50 years. mpf for any value of Sc at the rotation chosen can now be read off from this graph. Thus, if the land be purchased for £20 per acre, the financial yield, with a rotation of 50 years, will be about 3·42% ; for a rotation of 40 years it will be about 3·35%, showing that, with land at this price, 50 years is the more profitable rotation. With land at £10 per acre, the financial rotation

* This is a laborious process which may be lightened by the use of schedules as explained in Hiley's *The Economics of Forestry* (p. 138).

will be between 40 and 50 years, because the two rotation curves cross approximately on this line. To obtain the financial rotation for other soil values, additional curves must be drawn.

Schlich's graph provides the best method of determining

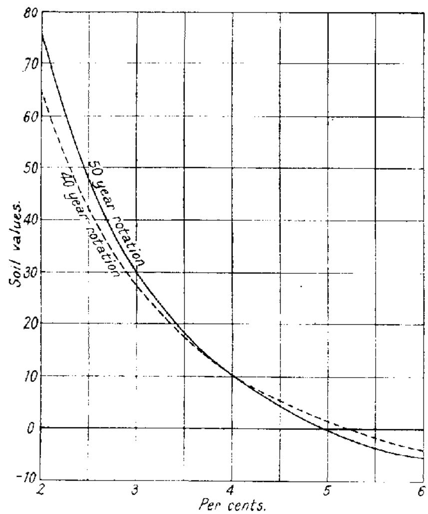


FIG. 16.—SCHLICH'S GRAPH FOR II QUALITY LARCH FROM TABLE II, p. 123.

the financial yield for any given rotation and soil cost; but it requires the calculation of a large number of rotation curves to determine the financial rotation for any soil value. The latter is more easily determined by preparing Hiley's indicator graph (*vide* Hiley's *The Economics of Forestry*), which is also the best method of representing graphically the results of a series of calculations covering the rotations represented by a single money yield table. It is prepared as follows, *vide* Fig. 17. With soil values as ordinates and rotations as abscissæ (Table II, p. 123), the figures under each per cent. are plotted and curves drawn for each rate per cent. It will be seen that

the 2% curve reaches its maximum at about 60 years, the 3% at about 50 years, the 4% at about 45 years, and the 5% between 40 and 45 years. If these maxima are joined up, it will be found that they lie on what is very nearly a straight line AB.

The financial rotation for any soil value is found where the S line meets the line AB. Thus if the land costs £10 per acre the financial rotation is 43 years. If it costs £50 per acre the rotation is 55 years.

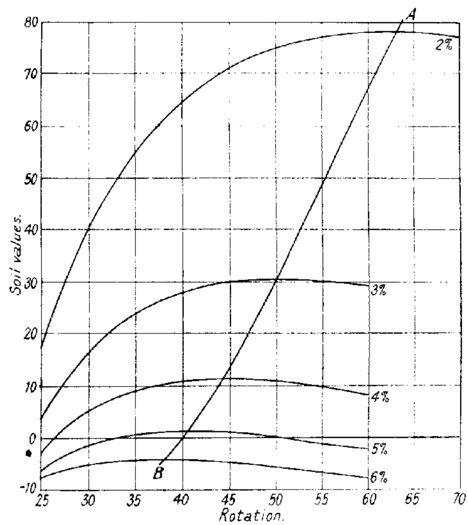


FIG. 17.—HILEY'S GRAPH FOR II QUALITY LARCH FROM TABLE II, p. 123.

The Financial Yield for any rotation and soil value is found by the position of the intersection of the S and r lines in relation to the per cent. curves. Thus, if land costs £11 per acre, the financial yield with a 50-year rotation is 4%. But, unless the point of intersection falls on or near a per cent. curve, the financial yield cannot be determined with accuracy direct from this graph. For example, to obtain the financial yield for a soil value of £50 and a rotation of 50 years it would be necessary

to plot soil values on the 50-year rotation line over the percentages as abscissæ, which results, of course, in Schlich's graph.

It has been pointed out (Section VI) that the financial rotation when calculated with a fixed value for " p " is independent of the soil cost. Calculated from the financial yield it is now found to vary with the soil cost. That this is so is obvious from the fact that in both cases the financial rotation is calculated from the same formula, but in the former with a fixed value for " p " and in the latter with a fixed value for " S." The fact, however, may lead to some doubt as to which is the correct method of calculating the financial rotation in any given case.

The matter may be explained as follows:—Faustmann's formula assumes, not only that money for all costs is borrowed at a fixed per cent. " p," but also that receipts during the rotation are invested at this same rate " p " in a reserve fund to pay off the debt; for this is the effect of multiplying Ta by $\frac{1{\cdot}0p^{r-a}}{1{\cdot}0p^r - 1}$. The financial yield method of calculating the financial rotation assumes, on the other hand, that the forest itself is the reserve fund in which receipts will be invested to give mpf. It would, therefore, seem that the correct plan is to choose that method which gives the more profitable reserve fund, *i.e.*, if mpf$>$p, to select the financial yield method, if mpf$<$p, to select the Se method. But it is hardly necessary to consider the latter case, since, if mpf$<$p, the project is one which will result in a loss and should not be undertaken. For example, referring to Table II (p. 123), under p = 4% we find the financial rotation is 45 years at which Se = £11·1. This coincides with the financial rotation from Hiley's graph, which also clearly demonstrates the fact that, for any soil cost above £11·1, 4% will not be earned and there will be a loss if money is borrowed at this rate. Should, however, the soil cost only £1 per acre, then the financial rotation from Hiley's graph is 41 years, at which rotation the forest reserve fund will yield over 5%. From which we may deduce that, if the maximum value of Se, with any fixed value of " p," is appreciably greater than Sc, then the correct financial rotation is more accurately determined from the financial yield.

VIII. Chapman's Financial Yield Formula (vide Forest Valuation, H. H. Chapman, 1915)

If thinnings are valueless, as is frequently the case in remote forests, the financial yield is more easily determined from Chapman's formula, which is as follows:—

Excluding thinnings, Faustmann's formula becomes,

$$S = \frac{Yr - C \times 1{\cdot}0p^r}{1{\cdot}0p^r - 1} - E$$

or $\quad S\,(1{\cdot}0p^r - 1) = Yr - C \times 1{\cdot}0p^r - E\,(1{\cdot}0p^r - 1)$

from which $S \times 1{\cdot}0p^r + C \times 1{\cdot}0p^r + E \times 1{\cdot}0p^r = Yr + S + E$

and $1{\cdot}0p^r = \dfrac{Yr + S + E}{S + C + E}$

from this formula the value of "p" could be calculated by logarithms but for the fact that, since $E = \dfrac{e}{\cdot 0p}$, an unknown value is introduced also into the right-hand side of the equation. Chapman gets over this difficulty by putting $E = \dfrac{e}{0{\cdot}0x}$, where x is as near an approximation to p as can be guessed. Then from the above formula a value of x, a nearer approximation to "p," is calculated. The second solution of the equation will give a value for "p" usually within 0·1% of the true value.

**IX. The Financial Rotation in Relation to the Indicating per cent.*

The meaning of Indicating Per Cent. (cpf) has been explained in Chapter I. It will be seen that all that is required to determine it are two valuations of the forest capital at short intervals, since it takes no account of any expenditure or income prior to the period considered. It is, therefore, particularly useful in the case of forests where little data are available. It will generally be determined for forests which are approaching maturity, and perhaps its chief value is to determine whether a wood, which has reached the age of technical maturity is financially

* This subject is dealt with more fully in Hiley's *The Economics of Forestry*, pp. 157 to 164.

ripe. This will be accomplished by comparing it with "p," the ruling per cent. as defined in Chapter I. If

cpf $>$ p the wood is not yet financially ripe.

cpf $=$ p the wood is financially ripe.

cpf $<$ p the wood is over ripe.

It is, of course, preferable to compare it with mpf, if data are available for determining the latter, and the relations existing between cpf and mpf should be clearly understood. It is only necessary to say that they are exactly similar to the relations obtaining between C.A.I. and M.A.I., dealt with in Part I, Chapter I, Section III. That is to say, cpf and mpf are the financial equivalents of C.A.I. and M.A.I. for volume, and may be used in the same way for ascertaining the financial rotation, as the latter are used for ascertaining the rotation of the maximum volume production.

Likewise the method of determining cpf is similar to the method of determining the current annual volume per cent. previously explained.

The following is the most simple method, and, though not absolutely accurate, is sufficiently so for all practical purposes.

Let Ym = value of the forest in the year m

,, Y_{m+n} = value of the forest n years later

,, e = Annual expenses.

N.B.—The value of the thinnings, made in the interval, will be included in Y_{m+n}, and it is therefore desirable that the year $m + n$ should be the year in which thinnings are made.

The total gross income over the period, including capital appreciation, will therefore be $Y_{m+n} - Y_m$; and, assuming that the income is equal for each year of the period,

$$\text{Average annual gross income} = \frac{Y_{m+n} - Y_m}{n}.$$

$$\text{Average annual net income} = \frac{Y_{m+n} - Y_m}{n} - e$$

Average value of the capital, including land

$$= \frac{Y_m + Y_{m+n}}{2} + S.$$

Then, since $$\text{cpf} = \frac{\text{Income}}{\text{Capital}} \times 100$$

$$\text{cpf} = \frac{\dfrac{Y_{m+n} - Y_m}{n} - e}{\dfrac{Y_m + Y_{m+n}}{2} + S} \times 100$$

$$= \frac{Y_{m+n} - Y_m - ne}{n} \times \frac{200}{Y_m + Y_{m+n} + 2S}.$$

$$= \frac{Y_{m+n} - Y_m - ne}{Y_m + Y_{m+n} + 2S} \times \frac{200}{n}$$ *Formula for indicating %.*

The inclusion in the formula of the soil value is necessary, since it always forms part of the forest capital. In civilized countries it often forms an important part, but, in less highly developed countries, the soil may have little or no value apart from the forest growing on it, and in such circumstances S may be excluded from the formula.

Example: From the Money yield table on p. 115 determine cpf between the ages of 40 and 45 years; where Sc = £5 and e = £·6

$$Y_{m+n} = \text{Yr at } 45 = £137$$

$$\text{Ym} = \text{Yr at 40 less thinnings in that year}$$

$$= £11[illegible] - £5{\cdot}2 = £10[illegible]{\cdot}8$$

hence formula becomes

$$\text{cpf at } 42\tfrac{1}{2} \text{ years} = \frac{137 - 10[illegible]{\cdot}8 - 3}{10[illegible]{\cdot}8 + 137 + 10} \times \frac{200}{5}$$

$$= 4{\cdot}[illegible]\%$$

X. Rotation of the Highest Income

This is the rotation which yields the highest net income irrespective of the time when the items of income and costs occur. If the influence of thinnings and price increment can be neglected and if annual expenses do not vary appreciably with alterations in the rotation, it is identical with the rotation of the highest final mean annual volume increment. If variations in price and the yield from thinnings have to be

considered, it will be determined for a normal series of age gradations from a money yield table by the formula

$$\text{Net income per acre} = \frac{Yr + \Sigma Ta - C - re}{r}$$

Where Yr = Final yield on 1 acre

Σ Ta = Yield from 1 acre thinned at each thinning period.

C = Costs of formation on one acre.

e = Annual maintenance costs of 1 acre.

Since this income is considered independently of the capital which produces it, there is no logical argument on which the adoption of the rotation of the highest income, *as such*, can be based; and it can be definitely stated that, where it is a question of the investment of fresh capital, as for example, an afforestation project, it need not be taken into consideration.

In practice, however, the *retention* of a rotation, which is in effect the rotation of the highest income, can often be justified on general grounds. A reduction of the rotation involves, in the first place, the placing of an additional quantity of timber on the market, which it may be unable to absorb except at greatly reduced prices; this will, of course, nullify financial calculations based on existing prices. It involves also a reduction in the capital invested in the forest, and for this surplus capital an investment must be found, either in the forest itself by increasing its area, or in some other security which will give a higher yield than before the reduction of the rotation. In this connection the forester in charge of State Forests will often be influenced by an argument which, though unsound in theory, has considerable justification in practice. Most Governments are in the habit of treating forest revenue as current income regardless of whether it represents real income or capital, and it is not, therefore, unnatural to hesitate in putting forward a proposal, which will result in reduction in the net annual income of a property without any corresponding increase in the value of the owners' other investments, or reduction of his indebtedness. It is useless for the forester to follow correct economic principles unless the owner does likewise. Finally, a reduction in the forest capital once made is not easy to replace; and, after it has been made, a change in prices and market conditions may alter the basis on which the financial calcula-

tions justifying the change have been made. This is particularly liable to happen where the calculations have been based on a ruling % "p," and not on the mpf; for, as has already been pointed out, this ruling per cent "p" is subject to very large fluctuations and is the main factor affecting the length of the financial rotation.

Hiley, in his interesting analysis of a Money Yield Table (*Economics of Forestry*), shows that there may be a difference of as much as 100 years in the financial rotation and the rotation of the highest income respectively, the former, in his example, being 40 years and the latter 140.

XI. *The Valuation of a Forest* (Hiley's *Economics of Forestry*, pp. 170–172, and Schlich, Vol. III, pp. 146–153)

The Wood Capital of a normal forest containing a normal series of age gradations is represented by the Spring G.S. Assuming 1 acre to be occupied by each age gradation the cost value of each age gradation of the G.S. will be as follows (*vide* formula for the cost value of a unit wood, p. 119), disregarding for the moment the value of thinnings:

Value of youngest wood just planted $= (Sc + E)(1{\cdot}0p^0 - 1) + C \times 1{\cdot}0p^0$

" " one-year-old wood $= (Sc + E)(1{\cdot}0p^1 - 1) + C \times 1{\cdot}0p^1$

" " two-year-old wood $= (Sc + E)(1{\cdot}0p^2 - 1) + C \times 1{\cdot}0p^2$

etc.

" " $r-1$-year-old wood (oldest) $= (Sc + E)(1{\cdot}0p^{r-1} - 1) + C \times 1{\cdot}0p^{r-1}$

The sum of the above expression is

$$(Sc + E)(1 + 1{\cdot}0p^1 + 1{\cdot}0p^2 + \ldots 1{\cdot}0p^{r-1}) - r(Sc + E) + C(1 + 1{\cdot}0p^1 + 1{\cdot}0p^2 + \ldots 1{\cdot}0p^{r-1}).$$

The first and last terms in the above are geometrical progressions with a common ratio of $1{\cdot}0p$, the number of terms r and the first terms Sc + E and C respectively, consequently the formula becomes

$$\frac{(Sc + E)(1{\cdot}0p^r - 1)}{{\cdot}0p} - r(Sc + E) + \frac{C(1{\cdot}0p^r - 1)}{{\cdot}0p}.$$

If there is one thinning at an age of "a" years, then it will

have occurred in the year " a " and in every year since that date ; the value of those thinnings will be the sum of

Ta	the value of the last thinning made in the year $r - 1$
$Ta \times 1{\cdot}0p$	,, ,, ,, ,, ,, ,, ,, ,, $r - 2$
$Ta \times 1{\cdot}0p^2$	,, ,, ,, ,, ,, ,, ,, ,, $r - 3$
	etc.

and $Ta \times 1{\cdot}0p^{r-a-1}$ the value of the first thinning made in the year a

giving a total of $\dfrac{Ta\,(1{\cdot}0p^{r-a} - 1)}{{\cdot}0p}$.

The value of these thinnings and of any other thinnings similarly calculated must be deducted from the above formula for costs, so that the formula for obtaining the cost value of a normal G.S. will be

$$\text{N.G.S.} = \frac{(Sc + E + C)\,(1{\cdot}0p^r - 1) - \Sigma Ta\,(1{\cdot}0p^{r-a} - 1)}{{\cdot}0p} - r\,(Sc + E).$$

To obtain the capital value of the *forest*, which includes the value of the land, $r \times Sc$ must be added to the above formula, which will then read

Cost Value of Forest

$$= \frac{(Sc + E + C)\,(1{\cdot}0p^r - 1) - \Sigma Ta\,(1{\cdot}0p^{r-a} - 1)}{{\cdot}0p} - rE$$

Example 1: Where Sc = £5 per acre, C = £10 per acre, e = 12s. per acre and p = 4% and using the money yield table on p. 115, the cost value of a normal forest of 30 acres worked on a rotation of 30 years will be

$$\frac{\left(5 + \frac{{\cdot}6}{{\cdot}04} + 10\right)(1{\cdot}04^{30} - 1) - 2{\cdot}5\,(1{\cdot}04^{15} - 1) - 2{\cdot}5\,(1{\cdot}04^{10} - 1) - 5{\cdot}2\,(1{\cdot}04^{5} - 1)}{{\cdot}04} - 30 \times \frac{{\cdot}6}{{\cdot}04}$$

$$= \underline{£1{,}574{\cdot}3} - 450 = £1{,}124{\cdot}3.$$

The above method of valuation is highly artificial as it can only be used for a forest which is approximately normal and the returns and expenses of which occur at approximately regular intervals. Whilst such calculations may be made to

support an economic forest policy, an existing forest could seldom, if ever, be valued in such a manner. For valuing a real forest a method based on the annual net income (*vide* Chapter II, Section 1 (c), p. 106) accompanied by an investigation into the degree to which this income was fairly representative of the capital value, would probably be more practicable.

The capital value of a normal forest based on net income may be worked out and compared with the cost value as determined in the above example; thus

Example 2: Taking the same figures as in the previous example

$$\begin{aligned}\text{Annual net income} &= Y30 + T15 + T20 + T25 - C - 30 \times c \\ &= £63{\cdot}4 + 2{\cdot}5 + 2{\cdot}5 + 5{\cdot}2 - 10 - 30 \times {\cdot}6 \\ &= £45{\cdot}6\end{aligned}$$

$$\text{The capital value producing this income} = \frac{100}{4} \times 45{\cdot}6 = \underline{£1{,}140.}$$

The amount is different from that previously obtained because 4% is not the amount actually earned by the forest capital, *i.e.*, it is not exactly the financial yield (*vide* Section VII, p. 128) for a rotation of 30 years and a soil cost of £5 per acre. For any rotation less than the financial rotation the capital value obtained by both methods will be the same provided p = mpf.

XII. Assessment of Damages

The most usual case in which the question of the payment of compensation will arise is that of the destruction of a wood by fire. The subject is a wide one involving a certain conflict of principles and can only be dealt with briefly here.* If the wood is a mature one it will probably be possible to assess a sale value. If it is a very young one, the compensation will be fairly assessed by the cost of replacement which will be determined from the formula for mGc in Section III of this chapter. If the wood, however, though not yet ripe for felling, is already of advanced age, a fairer method of assessing compensation is to determine the Expectation Value of the crop, that is to say the value of future yields less the value of future expenses discounted to the present time.

* For a fuller discussion of the subject see *Forest Valuation*, by H. H. Chapman.

Example: A wood which will be ripe and give a yield of Yr in the year r, and a thinning valued at Tn in the year n, is burned in the year m. What compensation should be paid?

The present values of the receipts from Formula II are

$$\frac{Yr}{1{\cdot}0p^{r-m}} + \frac{Tn}{1{\cdot}0p^{n-m}} \qquad (1)$$

From the above must be deducted the present value of the annual expenses required to produce these receipts, namely:

$$\frac{e \times (1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m} \times {\cdot}0p} \text{(from Formula VI)} \qquad (2)$$

The owner will, however, remain in possession of the soil, the annual value of which may be considered likewise as an annual expenditure incurred in producing the above yields, and should likewise be deducted in assessing the compensation to be paid.

The annual rental of the soil $= S \times {\cdot}0p$, and the present value of this rental for $r - m$ years $= S \times {\cdot}0p \times \frac{(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m} \times {\cdot}0p}$ (from Formula VI)

$$= \frac{S \times (1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}} \qquad (3)$$

The formula for the expectation value of an immature wood will therefore be

$$1 - (2 + 3) = \frac{Yr - (S + E)(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}} + \frac{Tn}{1{\cdot}0p^{n-m}}$$

In practice there may be great difficulty in deciding on the value of S in the above formula. If the land has a definite sale value this value may be applied. If, as frequently is the case in remote districts, no value can be attached to the land apart from the forest crop it produces, then no deduction should be made from the compensation to be paid on this account. On the other hand, the land may have a very definite value and the payer of compensation may claim a reduction on the ground that the owner can exercise his option of selling the land, S of course always being greater than $\frac{S\,(1{\cdot}0p^{r-m} - 1)}{1{\cdot}0p^{r-m}}$, the value given to S in the formula. In practice also other considerations will almost always arise, such as whether or not destruction is complete and whether special expenses have to be incurred in clearing and preparing the land for the new crop.

CHAPTER V

*Choice between Agriculture and Forestry

It is sometimes required to determine whether a given piece of land will yield higher returns when devoted to agriculture or forestry respectively. Comparison may be made as follows :—

Agricultural (or grazing) land in any district has usually a well recognized sale and letting value from which the financial yield from agriculture may be determined. This may be compared with the financial yield from forestry after deciding the species to be grown, assessing the value of the locality for that species, preparing a money yield table and estimating costs. Instead of comparing the two financial yields, Se, in relation to the forest species chosen, may be calculated for different rotations, placing p = financial yield of agriculture, and the highest value of Se compared with the agricultural value S. Thus :

Example: A piece of land has a capital value of £10 per acre. Let for agricultural purposes it gives a net yield to the owner of 8s. per acre. It is suitable for growing No. II quality Larch, for which the returns are given in the money yield table on p. 115, and the cost of formation of which is estimated at £5 per acre and the annual expenses 6s. Which will be the more profitable, agriculture or forestry ?

The financial yield from agriculture $= p = \frac{8}{200} \times 100 = 4\%$.

Consequently the values of Se with p = 4% must be determined for different rotations. This has already been done in Table II, p. 123, and they are as follows :

r	*Se*
40	10·5
45	11·1
50	10·4

Since Se at each of these rotations exceeds £10, forestry will be more profitable.

* The method of comparison used here follows Schlich.

To compare forest financial yields with the agricultural financial yield, either Schlich's or Hiley's graph must be prepared. Referring to these, compiled with the above data on pp 126 and 127, we find that mpf culminates at a rotation of about 43 years with a value of 4·1%, showing that forestry gives a slightly higher return than agriculture in this instance.*

* The comparison is complicated in Great Britain by the subsidy given by the State to private owners of forests in the form of remissions of income tax and death duties. Direct planting subsidies are also given, which of course reduce the costs of formation. Details of these remissions and subsidies are given in the British Forestry Commission's Leaflet No. 12, and their effect is explained in Hiley's *Management of Woodlands*.

CHAPTER VI

General Conclusions on the Application of Financial Tests to Forest Management

THE value of the application of financial tests to the management of forests has been questioned on many grounds, the most reasonable of which are the uncertainty of the data employed in the calculations, and the probability that they will change during the period for which the calculations are made. In comparison with other forms of human enterprise this uncertainty is, of course, a matter of degree; it exists in all forecasts of the future, and few balance sheets of industrial concerns will provide an accurate reflection of the forecasts made in the prospectus, however carefully drawn up. Proprietors nevertheless demand such forecasts, and, apart from their practical value in forest management, an understanding of the problems involved is essential for all those who would direct or influence the forest policy of individuals or communities.

As regards the practical value of the application of financial tests, one can only say that it will depend on the circumstances of each individual case.

Over a considerable extent of the continent of Europe, where forestry has reached the highest stage of development, the management of State forests is carried on without any consideration whatever being paid to the earning power of money. This is due to the feeling that the national interest is best served by growing a class of produce, which, experience has shown, is always likely to be in demand, and that the national forests represent an asset whose intrinsic capital value cannot be adequately expressed by such a fluctuating standard as money represents. It is, of course, useless applying a financial test, which is certain to indicate the desirability of reducing the existing rotation, if one has already made up one's mind to be guided by other considerations.

The danger of a drastic reduction in the forest capital employed, in order to obtain a higher financial yield, has already been referred to in discussing the rotation of the highest income.

Where it is a question of the felling and replacement of a natural forest it is arguable that the costs of replacement are part of the costs of realization and should be debited against the present and not against future yields, a procedure which would, of course, have a considerable effect on the length of the financial rotation.

Even in cases where a forest has to be created, the practice of debiting the future values of costs against future yields calculated at the *current rates for produce* will, if the minimum technical rotation is a long one, probably give a false idea of the profitableness of the undertaking. The reason for this is that (as history shows) over long periods the value of money falls in terms of labour and produce ; so that costs, incurred in the early part of the rotation, will constitute a much smaller proportion of the final yield than a forecast made on current rates would lead one to suppose.

The above remarks show that it is dangerous to allow forest management to be unduly influenced by purely financial considerations and justify the statement in Chapter IV of Part I that the rotation chosen in practice is usually a combination of the silvicultural and technical, with perhaps the application of a financial test.

Where very short rotations are compatible with technical and silvicultural requirements, the pure financial rotation may properly be adopted. Afforestation schemes must as a rule be given a financial justification in order to obtain the necessary funds, and, as a result, the rotations adopted will generally be lower than those prevailing in longer established forests. Should subsequent changes in conditions show that the former rotations are too short they can be lengthened later without much inconvenience. Moreover alterations in the relative values of money and produce may not be accompanied by any alteration in the relative values of different forest products, and therefore financial calculations made to determine the most profitable species to grow and the most profitable treatment may remain valid throughout comparatively short rotations.

It has been shown that the financial results of Forestry depend very largely on initial expenditure and the rate of

interest charged. The former consideration indicates the desirability of applying financial tests to decide such matters as the planting distance which may be adopted—within the limits of good silviculture—having regard to the effect of planting distance on future weeding, cleaning and pruning expenses and the yield from thinnings. The latter consideration indicates the desirability of choosing periods when interest rates are low for special activity in afforestation.

APPENDIX I

Terms used in Forest Management

(As approved by the Empire Forestry Conference, 1928)

Age Class ...	... Trees falling within definite age limits grouped together for purposes of management.
Age Class period	... The number of years within the limits of a given age class.
Age, exploitable	... See Exploitable Age.
Area, working plan	... See Working Plan Area.
Block	... A natural main division of a forest, generally bearing a local proper name.
Block, periodic...	... See Periodic Block.
Circle, working	... See Working Circle.
Compartment ...	... A territorial unit permanently defined for purposes of description and record. (Preferably designated by Arabic numerals—1, 2, 3, 4.)
Conversion period	... The period during which a change from one silvicultural system to another is effected.
Coupe	... A felling area (usually annual unless otherwise stated).
Cutting section	... A subdivision of a felling series, formed with the object of regulating cuttings in some special manner.
Cycle, felling ...	... See Felling Cycle.
Cycle, thinning	... See Thinning Cycle.
Exploitable age	... The average age at which trees normally attain exploitable size.
Exploitable size	... The girth or diameter determined upon as the normal size for the felling of mature trees in order to fulfil the objects of management.

Felling cycle ...	... The time which elapses between successive principal fellings on the same area.
Felling series ...	... A series with a separate calculation of the yield, formed to control felling and regeneration.
Period ...	... A subdivision of a rotation.
Period, age class	... See Age class period.
Period, conversion	... See Conversion period.
Period, working plan	See Working plan period.
Periodic Block	... The part or parts of a forest set aside to be regenerated or otherwise treated during a period.
Plan, working	... See Working Plan.
Planting series	... A series formed to control planting operations.
Rotation ...	... The number of years determined upon between the formation or regeneration and the final felling of a forest crop.
Section, cutting	... See Cutting section.
Series	... A management unit in which the object is to maintain or create a normal representation of age gradations. (See Felling Series and Planting Series.)
Series, felling ...	... See Felling series.
Series, planting	... See Planting series.
Size, exploitable	... See Exploitable size.
Sub-compartment	... A subdivision of a compartment, generally of a temporary nature, differentiated for special description and treatment. (Preferably designated by small letters—a, b, c, d.)
Thinning cycle	... The time which elapses between successive thinnings on the same area.
Working circle	... The area (forming the whole or part of a working plan area) organized with a particular object and subject to one and the same silvicultural system and the same set of working prescriptions. *Note.*—In certain circumstances two or more working circles may overlap.

Working plan ...	... A written scheme of management aiming at a continuity of policy controlling the treatment of a forest.
Working plan area	... The area covered by a single working plan.
Working plan period	The time for which detailed prescriptions are laid down in a working plan.

APPENDIX II

FUTURE VALUE OF £1 IN N YEARS AT P% COMPOUND INTEREST
$= 1{\cdot}0p^n$

Years.	2%	3%	4%	5%	6%
1	1·020	1·030	1·040	1·050	1·060
2	1·040	1·061	1·082	1·102	1·124
3	1·061	1·093	1·125	1·158	1·101
4	1·082	1·125	1·170	1·216	1·262
5	1·104	1·159	1·217	1·276	1·338
6	1·126	1·941	1·265	1·340	1·418
7	1·149	1·230	1·316	1·407	1·504
8	1·172	1·267	1·369	1·477	1·594
9	1·195	1·305	1·423	1·551	1·689
10	1·219	1·344	1·480	1·629	1·791
15	1·346	1·558	1·801	2·079	3·397
20	1·486	1·806	2·191	2·653	3·207
25	1·041	2·094	2·666	3·387	4·291
30	1·811	2·427	3·243	4·322	5·743
35	2·000	2·814	3·947	5·516	7·686
40	2·208	3·262	4·801	7·040	10·284
45	2·438	3·782	5·841	8·985	13·765
50	2·692	4·384	7·107	11·467	18·416
55	2·972	5·082	8·647	14·636	24·651
60	3·281	5·892	10·520	18·679	32·980
65	3·623	6·830	12·800	23·840	44·146
70	4·000	7·918	15·572	30·426	59·057
75	4·416	9·179	18·945	38·833	79·059
80	4·875	10·641	23·050	49·561	105·760
85	5·383	12·336	28·041	63·254	141·529

Years.	2%	3%	4%	5%	6%
90	5·943	14·300	34·119	80·730	189·470
95	6·562	16·578	41·511	103·035	253·544
100	7·245	19·219	50·505	131·501	339·312
110	8·831	25·828	74·760	214·202	607·659
120	10·765	34·711	110·623	348·912	1088·228
130	13·123	46·649	163·808	568·341	
140	15·996	62·692	242·475	925·767	
150	19·500	84·253	358·923	1507·977	
200	52·485	369·356	2550·750	17292·581	

Note.—To obtain values for intermediate years, multiply.

E.g., Where n = 32 and p = 4%

$$1{\cdot}04^{32} = 1{\cdot}04^{30} \times 1{\cdot}04^{2} = 3{\cdot}243 \times 1{\cdot}082 = 3{\cdot}509$$

APPENDIX III

Extract from a Government of India Resolution on Forest Policy

The object of forest administration is the public benefit.

(1). The sole object with which State forests are administered is the public benefit. In some cases the public to be benefited are the whole body of tax-payers; in others the people of the tract within which the forest is situated; but in almost all cases the constitution and preservation of a forest involve, in greater or less degree, the regulation of rights and the restriction of privileges of user in the forest area which may have previously been enjoyed by the inhabitants of its immediate neighbourhood. This regulation and restriction are justified only when the advantage to be gained by the public is great; and the cardinal principle to be observed is that the rights and privileges of individuals must be limited otherwise than for their own benefit, only in such degree as is absolutely necessary to secure the advantage.

Classification of forests.

(2). The forests of India, being State property, may be broadly classed under the following headings:—

(*a*) Forests, the preservation of which is essential on climatic or physical grounds.
(*b*) Forests which afford a supply of valuable timbers for commercial purposes.
(*c*) Minor forests.
(*d*) Pasture lands.

It is not intended that any attempt should be made to class existing State forests under one or other of these four heads. Some forests may occupy intermediate positions, and parts of one and the same forest may fall under different heads. The classification is useful only as affording a basis for the indication of the broad policy which should govern the treatment of each class respectively; and in applying the general policy, the fullest consideration must be given to local circumstances.

(a). Forests of which the preservation is essential.

(3). The first class of forests are generally situated on hill slopes, where the preservation of such vegetation as exists, or the encouragement of further growth, is essential to the protection from the devastating action of hill torrents of the cultivated plains that lie below them. Here the interests to be protected are important beyond all comparison with the interests which it may be necessary to restrict ; and so long as there is a reasonable hope of the restriction being effectual, the lesser interests must not be allowed to stand in the way.

(b). Large timber forests. To be managed on commercial lines subject to the satisfaction of the needs of the neighbouring population.

(4). The second class of State forests includes the great tracts from which our supply of the more valuable timbers—teak, sal, deodar, and the like—is obtained. They are for the most part (though not always) essentially forest tracts and encumbered by very limited rights of user and when this is the case, they should be managed mainly on commercial lines as valuable properties of, and sources of revenue to, the State. Even in these cases, however, customs of user will, for the most part, have sprung up on the margins of the forests ; this user is often essential to the prosperity of the people who have enjoyed it ; and the fact that its extent is limited in comparison with the area under forest renders it the more easy to continue it in full. The needs of communities dwelling on the margins of forest tracts consist mainly in small timber for building, wood for fuel, leaves for manure and fodder, thorns for fencing, grass and grazing for their cattle and edible forest products for their own consumption. Every reasonable facility should be afforded to the people concerned for the full and easy satisfaction of these needs if not free (as may be possible where a system of regular cuttings has been established) then at low and not at competitive rates. It should be distinctly understood that considerations of forest income are to be subordinated to that satisfaction.

Opening of forest to cultivation.

(5). It should also be remembered that, subject to certain conditions to be referred to presently, the claims of cultivation are stronger than the claims of forest preservation. The pressure

of the population upon the soil is one of the greatest difficulties that India has to face, and that application of the soil must be generally preferred which will support the largest numbers in proportion to the area. Accordingly, wherever an effective demand for culturable land exists, and can only be supplied from forest areas, the land should ordinarily be relinquished without hesitation; and if this principle applies to the valuable class of forests under consideration it applies *a fortiori* to the less valuable classes which are presently to be discussed.

Conditions on which cultivation should be permitted.

(6). Mention has been made of certain conditions to which the application of the principle laid down in the preceding paragraph should be subject. They have for their object the utilization of the forest area to the greatest good of the community. In the first place, the honeycombing of a valuable forest by patches of cultivation should not be allowed, as the only object it can serve is to substitute somewhat better land in patches for sufficiently good land in large blocks, while it renders the proper preservation of the remaining forest area almost impossible. The evil here is greater than the good. In the second place, the cultivation must be permanent. Where the physical conditions are such that the removal of the protection afforded by forest growth must result, after a longer or shorter period, in the sterilization or destruction of the soil, that case falls under the principle discussed in paragraph (3). So, again, a system of shifting cultivation, which denudes a large area of forest growth in order to place a small area under crops, costs more to the community than it is worth, and can only be permitted, under due regulation, where forest tribes depend on it for their sustenance. In the third place, the cultivation in question must not be merely nominal, and an excuse for the creation of pastoral or semi-pastoral villages which do more harm to the forest than the good they reap from it. And in the fourth place cultivation must not be allowed so to extend as to encroach upon the minimum area of forest which is needed in order to supply the general forest needs of the country or the reasonable forest requirements, present and prospective, of the neighbourhood in which it is situated. In many tracts cultivation is practically impossible without the assistance of forests, and it must not be allowed to destroy that upon which its existence depends.

(c). Minor forests to be used chiefly for the supply of local needs.

(7). The third class of forests includes those tracts which, though true forests, produce only the inferior sorts of timber or the smaller growths of the better sorts. In some cases the supply of fuel for manufactures, railways and like purposes is of such importance that these forests fall more properly under the second class, and must be mainly managed as commercial undertakings. But the forests now to be considered are those which are chiefly useful as supplying fuel and fodder or grazing for local consumption; and these must be managed mainly in the interests of the population of the tract which supplies its forest requirements from this source. The first object to be aimed at is to preserve the wood and grass from destruction; for user must not be exercised so as to annihilate its subject, and the people must be protected against their own improvidence. The second object should be to supply the produce of the forests to the greatest advantage and convenience of the people. To these two objects all considerations of revenue should ordinarily be subordinated.

But revenue should not altogether be forgone.

(8). It must not be supposed from the preceding remarks that it is the intention of the Government of India to forgo all revenue from the large areas that are valuable chiefly for the fuel and fodder which they yield. Cases must be distinguished. Where the areas in question afford the only grazing and the only source of supply of fuel to villages which lie around or within them, the necessities of the inhabitants of these villages must be treated as paramount, and they should be satisfied at the most moderate rates, and with as little direct official interference as possible. But where the villages of the tract have already ample pasture grounds attached to their cultivation and owned and managed by themselves, and where the crown lands merely supplement these pastures, and afford grazing to a nomad pastoral population, or to the herds which shift from one part of the country to another with the changes of the season, Government may justly expect to reap a fair income from its property. Even in such cases, however, the convenience and advantage of the graziers should be studiously considered, and the inhabitants of the locality, or those who habitually graze over it, should have a preferential claim at rates materially lower than might be obtained in the

open market. It will often be advantageous to fix the grazing demand upon a village or a nomad community for a year or a term of years. The system, like every other, has difficulties that are peculiar to it, but it reduces the interference of petty officials to the lowest point and minimizes their opportunities for extortion and oppression. Where grazing fees are levied *per capita*, free passages are often given to a certain number of cattle. In such cases the cattle which are to graze free should include, not only the oxen which are actually employed on the plough, but also a reasonable number of milch cattle and calves. A cow or a buffalo is as much a necessity to a cultivator, using the word necessity in a reasonably wide sense, as is a plough-bullock; and in many parts the oxen are bred in the village.

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